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ABSTRACT

This technical report describes a digital computer program on the spatial structure of agricultural production and how it can be used in economic geography courses. Chapters one through four, respectively, (1) examine the use of digital computers in the teaching of college geography, (2) analyze the von Thunen theory which postulates laws that influence the prices of agricultural products and the way in which price variations are subsequently translated into patterns of agricultural land use, (3) describe the Landuse program which is based upon the von Thunen model, and (4) present six cases which demonstrate the versatility, flexibility, and applicability of the program. The appendix includes detailed operating and key punching instructions for the Landuse program and for computer programs in general. Also included is a distribution address of the Geography Program Exchange (GPE) which has been established to assist universities and other non-profit organizations with the interchange of computer software that relates to problems of geographic nature. (Author/DE)

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GEOGRAPHIC TECHNICAL PAPER SERIES

LANDUSE:

A Computer Program for Laboratory Use in Economic Geography Courses

Duane F. Marble
Bruce M. Anderson

COMMISSION ON COLLEGE GEOGRAPHY
TECHNICAL PAPER NO. 8

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LANDUSE:
A COMPUTER PROGRAM FOR LABORATORY USE IN ECONOMIC GEOGRAPHY COURSES

by

Duane F. Marble
and
Bruce M Anderson

Northwestern University

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FOREWORD

The Technical Papers are explanatory manuals for the use of both instructors and students. They are expository presentations of available information on each subject designed to encourage innovation in teaching methods and materials. These Technical Papers are developed, printed, and distributed by the Commission on College Geography under the auspices of the Association of American Geographers with National Science Foundation support. The ideas presented in these papers do not necessarily imply endorsement by the AAG. Single copies are mailed free of charge to all AAG members.

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CHAPTER I

DIGITAL COMPUTERS AND THE TEACHING OF COLLEGE GEOGRAPHY

Although the large digital computer represents a relatively recent innovation in American universities, it is already established as a major tool for research geographers. There is, in geographic research as in other disciplines, a definite interaction between tools and problems. Some problem areas may lie dormant for a period of years or even decades because the necessary research tools are unavailable. When a new research tool becomes available, either through primary innovation or through the transfer of knowledge from workers in other disciplines, there is frequently a surge of interest in topics which had previously been set aside, as well as development of new areas of investigation.

An example of this phenomenon within geography can be seen in the impact of the high-speed, digital computer on problems of multivariate regionalization. The approach to an optimal multivariate classification of areas based upon a comparison of between region and within region variances had been developed, but empirical implementation was forced to wait until computing machinery capable of handling the calculations became available. When it did, a strong upsurge of empirical interest in this topic followed. These empirical investigations raised, in turn, additional theoretical questions and the cycle advanced through another phase.

Parallel to the development of the computer as a research tool in many disciplines has been its use as an instructional aid. Early applications of the digital computer in instruction involved the use of the machine to permit students to handle problems of a size and scale of complexity that had hitherto been impossible within the standard classroom situation. In engineering, for example, students began to handle problems which were considerably more realistic than the traditional, hand-computed examples. This proved quite fruitful, and the introduction of the computer as a laboratory tool proceeded rapidly in many engineering disciplines and, in some schools, its use has been firmly established for well over a decade. An illuminating discussion of this approach can be found in the report of the Ford Foundation project at the College of Engineering of the University of Michigan [17]. Instructional use of the computer has lagged considerably in most of the social sciences, though there have been some recent attempts within geography and other social science disciplines to provide programs of this nature. For example, see the work by Rushton [11] as well as the more elaborate urban simulations such as that of Wärneryd [19].

Recent technological developments have permitted the central computer to handle a large number of users on a nearly simultaneous, real-time basis. Efficient

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time-sharing systems permit a number of users, equipped with remote terminals, to utilize a central computer through the intermediate efforts of a complex supervisory system which examines the priorities and needs of each user and allocates to him only that portion of the main computer's capacity required for his work, and for only that period of time which is necessary to process the next step in his problem. Much of the capacity of these time-sharing systems arises out of the great disparity between the internal computation speeds of the central computer and the speed at which information can be transmitted and received from the remote terminals. This disparity can be seen in an examination of the relative printing rates of most of the commercially available remote terminals. These are very slow when compared with the main computer's dedicated peripheral printers and the speed factor is frequently on the order of 250 or 300:1, if not more. Even with this speed differential, the main computer is frequently bound by the capacity of its "high speed" printers and will operate two or more of them simultaneously in order to attain greater output volumes.

The introduction of time-sharing facilities in many universities has prompted the development of computer assisted instruction (CAI). There has been a great deal of interest in CAI on all educational levels ranging from preschool children to college graduates, and many of the CAI developments in college geography are discussed in previous technical papers of the Commission on College Geography. In the standard CAI environment, the time-sharing computer interacts with one or more students utilizing remote terminals. A series of queries are presented by the computer, based upon a program previously prepared by the instructor, with each query in the program designed to illuminate a particular point relating to the topic under discussion (*e.g.*, map projections, water balance, etc.). After each query the student presents a response which the computer checks against a series of stored answers which have also been provided by the instructor, and then, depending upon the nature of the student's response, branches to another section of the program. Internal loops are common in these programs so that the student can be given an opportunity to re-examine material that is giving him difficulty. This "match, branch and loop" format is basic to most CAI programs. In many cases, the CAI programs are not really computational ones since they utilize only a very small portion of the available facilities of the central computer and are normally restrained to "match, branch and loop" operations. Although many CAI programs are run on large, third generation digital computers which provide the necessary time-sharing environment, the "match, branch and loop" mode of these programs does not really require the facilities of a computer of such power and some universities have responded by installing smaller computers which handle only CAI work. An informal survey conducted in 1970 indicated that only a handful of U.S. geography departments were currently utilizing CAI on either an experimental or operational basis, but that many of the departments had a strong interest in future uses of CAI.

It is possible to utilize the basic "match, branch and loop" format of the CAI program in combination with the major computational capacity of the machine.

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This could be done, for example, in a CAI unit dealing with problems of spatial optimization which, after providing instruction in the basic elements of linear programming and its application to spatial problems, would require the student to set up a specific problem in a linear programming format. The CAI program would call upon a resident linear programming routine to solve the student's problem and then display the results of this computation to the student together with an appropriate commentary. Because of the multi-processing nature of large modern computers, the CAI program could continue the foreground conversation with the student while the linear programming problem was running in the background. This represents a rather sophisticated use of CAI, but one that will be increasingly utilized. There are, however, several basic disadvantages to current CAI approaches which arise largely out of the computing environment as it stands at the present time. These include:

1) *The lack of comparability of the programs.* A great variety of CAI programming languages are available, some of which can be utilized only on specific machines, and sometimes only at specific installations. Other languages which appear to have greater comparability, particularly the BASIC language, suffer from a lack of standardization which inhibits the easy transfer of CAI programs from one installation to another.
2) *The slow printing speed of most remote terminals.* An inexpensive terminal tends to print so slowly that there is difficulty in retaining student attention, while terminals with higher printing speeds are, at present, unduly expensive.
3) *The difficulty of producing any form of graphic output at a remote terminal.* This is an impediment which appears particularly critical for geographic applications since many geographic CAI applications would benefit greatly from the output of simple graphics as well as maps. Available graphics terminals are currently both specialized and expensive, while printing a one page map at a Teletype terminal utilizing a printing area of, say 50 rows by 70 columns would require the printing of 3,500 map elements (characters) and would take five minutes or more. As terminals with higher printing speeds become available, this time will be cut to two minutes or under, but even this is not adequate. At present, then, geographically based exercises which require more than exceedingly modest amounts of graphic output, or which require map output, can be carried out only on expensive remote terminal installations or by utilizing the batch processing capability of the central computer.

It must be emphasized that these problems will undoubtedly be overcome in the next few years by rapid increases in the level of computer and communications technology. It would appear that a profitable interim approach would be to develop a series of more complex programs based on highly standardized languages, such as FORTRAN, and oriented toward batch processing rather than time-sharing.

As technology improves, these programs could be converted to the "foreground-background" CAI mode mentioned earlier. Experiments have shown that the

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program described in this paper, LANDUSE, can be run effectively in such a configuration, but to do so at present requires the use of a high-speed terminal, a specialized communications link and a 300 line/minute printer. This type of installation has a rental rate significantly in excess of $1,000/month. Within a period of four to six years, it should be possible to incorporate these programs into a CAI environment in which such equipment configurations are less expensive and much more common than they are today.

The LANDUSE Program

The program described in this paper, LANDUSE, is designed as a laboratory tool for use in economic geography courses at both the beginning and intermediate levels. It is not a CAI program in the current sense of that term, since it does not utilize the basic "match, branch and loop" structure. It is, rather, directly related to the third type of instructional program termed "generative" by Huke, Fielding and Rummage [6]. Programs of this nature permit students to enter parametric information into a process model and to note the fashion in which the model operates upon the information to produce the desired output. Students are expected to interpret the patterns produced with reference to the theoretical concepts contained in the process model. The impact of changes in the system can also be explored through alterations of the parameter values on successive runs of the program. In this manner, the program assists the students in attaining an understanding of some interrelationships present in complex models of spatial environments. A similar approach to industrial location is embodied in the computer model developed by Smith and Lee [13].

LANDUSE deals with a simple model of agricultural land use (the basic von Thünen model), which is relatively rich and capable of successive complication. The program was developed after an examination of an early version of the program prepared by Rushton [11]. An entirely new program was prepared, rather than modify the Rushton program, in order to provide a number of additional features in an efficient fashion. These include:

1) replication of the basic case consisting of a single market center and simple concentric rings,
2) introduction of one or more space distorting transportation routes into the system in a completely flexible form, and
3) an ability to change the scale of analysis in a flexible but simple fashion.

Chapter II provides a summary of the process theory which underlies the operation of the program. The third chapter describes the structure of the program and some of the problems encountered in classroom use. The final chapter presents six selected cases which demonstrate the flexibility and scope of the LANDUSE program.

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CHAPTER II

AGRICULTURAL LAND USE: A BRIEF THEORETICAL STATEMENT

The basic theory pertaining to the spatial structure of agricultural production originated a century and a half ago in the work of a German economist, Johann Heinrich von Thünen. Since then, other researchers have produced more complete and complex statements of this theory but we are concerned here largely with the simple case as originally presented in von Thünen's classic book, *The Isolated State* [18]. In this work von Thünen attempted to discover those laws which influence the prices of agricultural products and the way in which price variations are subsequently translated into patterns of agricultural land use. Basically, he was concerned with competition between various agricultural products and farming systems for the use of specific plots of land. A primary assumption of his model was that on each piece of land, the activity which yielded the highest net return from utilization of the parcel would be found and that competing activities would be displaced to locations where they, in turn, would yield the highest net return.

To facilitate discussion of this problem, von Thünen utilized a hypothetical case – his "isolated state" – wherein he posited the existence of a market center located at the center of a large, fertile plain which contained no transportation routes. The undifferentiated plain in which transfer costs are a simple function of distance, the "isotropic plain," appears as a starting point in many geographic theories. Von Thünen further assumed that throughout the plain the soil was equal in quality and that the agricultural productivity of specific plots of land did not vary from one location to another. At some great distance from the town the plain turned into an uncultivated wilderness which effectively cut off all communication between the "isolated state" and the outside world. In this isolated community, the central town would supply the surrounding rural area with all manufactured products and, in return, would obtain all of its agricultural inputs from enterprises located on the plain. The problem as posed by von Thünen was: *what pattern of cultivation would take shape, given the stated conditions, and how would farming systems in different portions of the plain be affected by their distance from the central town?* An explicit assumption in his work was that all agricultural entrepreneurs made decisions in an economically rational fashion. That is, entrepreneurs responded only to profit maximization as an optimizing goal and were assumed to be in possession of complete information pertaining to all choices.

Economic Rent and Location Rent

As the basis of his analysis, von Thünen introduced the concept of *economic rent*. While he developed this notion independently, it had also been introduced a

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few years earlier by an English economist, David Ricardo, who was interested in the way certain factors conditioned agricultural production decisions. He was, however, concerned primarily with variations in productivity rather than with the impact of purely spatial factors. The Ricardian version of economic rent, as contrasted to that of von Thünen, is clearly set forth by Michael Chisholm in his book, *Rural Settlement and Land Use* [2].

The concept of economic rent is central to many questions of land use competition and it is utilized in the von Thünen model to provide a means whereby this competition is resolved in a rational fashion. The observed gap between revenues and costs represents economic rent in a technical sense. Von Thünen observed that Ricardo had based his discussion of the nature of economic rent upon differences in the inherent productivity of various parcels of agricultural land, but that the same phenomena would arise if productivity were held constant and the parcels were subjected to varying transportation charges based upon the cost of moving their production over different distances to the central market. In Ricardo's case, differential fertility of the plots influenced the level of gross returns, whereas in von Thünen's model, gross returns remained constant, but the cost of transportation varied with distance to the market.

The two cases are quite similar, but recent literature has tended to apply the term, "location rents" to those economic rents arising solely out of differences in location. This serves to differentiate them from more general scarcity rents which may arise from factors such as simultaneous variations in productivity as well as location. It should be made clear, however, that location rents constitute a specially defined subclass of general economic or scarcity rents and are identical to the latter only in the case wherein location is the only factor differentiating the parcels of land.

Given the assumption that we are dealing with a finite group of activities (which in themselves may consist of fixed bundles of subactivities, e.g., crop rotation schemes) it is then possible to view competition for the use of agricultural land as equivalent to the following process: each entrepreneur wishing to engage in an activity evaluates the utility of a given parcel for carrying out a specific activity and determines the level of rent which can be expected. This figure represents the maximum amount that the operator will be willing to bid for use of the parcel of land since any bid higher than this would require that the activity in question be operated at a loss. The bids for use of the parcel by various entrepreneurs desiring to undertake different activities may be ranked and the maximum identified. The activity associated with this maximum bid will then become the one which occupies that particular unit of land. This notion may be extended to non-agricultural activities, of course, and is roughly equivalent to the "highest and best use" notion which is frequently encountered in the urban land economics literature. In fact, a significant proportion of the current theory dealing with the internal spatial structure of the city rests upon the extension of this notion of location rents to form a basis for land use competition in the city, e.g., Alonso [1].

A Mathematical Statement of the von Thünen Model

In his original work, von Thünen was concerned with specific cases, but he did produce a general statement relating location rent to distance from the market center. Typically the basic von Thünen model can be stated as a simple linear equation:

$$R_i = Y_iP_i - Y_iC_i - Y_iT_iD = Y_i[P_i - C_i - T_iD], (i = 1,\ldots,n) \qquad (1)$$

where: R_i = location rent for the i^{th} activity on a specific parcel of land
Y_i = total production/unit of land for the i^{th} activity
P_i = unit price at the market for the i^{th} activity
C_i = unit production cost for the i^{th} activity
T_i = transport charge/unit/kilometer for the i^{th} activity
D = airline distance of the parcel of land from the market in km.

This equation states that the bid rent for activity *i* at a specific parcel is equal to the gross returns on production from that parcel (Y_iP_i), less the total cost of production (Y_iC_i), less the cost of moving that production to the market (Y_iP_iD). The simplest situation is obtained when we assume the existence of an isotropic transport plain in which T_i is a linear function of distance and is assumed to have an intercept of zero, i.e., there are no terminal charges in the system. It is also normally assumed that productivity is constant over the plain. That is, Y_i does not vary locationally within the system and that a similar condition holds with respect to unit production costs thus yielding a constant value, C_i, for every parcel. The unit price at the market is also assumed to be constant and the market will absorb, at that price, any amount which is offered.

For a specific activity, these assumptions leave us with identical net returns ($Y_iP_i - Y_iC_i$) excluding transport costs for every parcel on our hypothetical plain. The only variations in rent are then introduced by variations in transfer costs (Y_iT_iD) which are based entirely upon differences in the value of D. That is, when the parcel is located at the market site the third term in equation (1) is zero and location rent is equal to gross returns minus total cost of production. As parcels further and further from the market are considered, the size of the third term (Y_iP_iD) in the equation increases. At some distance from the market transport charges will be equal to gross returns and the rent will fall to zero. This distance marks the limit of feasible cultivation for the activity since production beyond this point would be unprofitable. The term relating to unit production costs, C_i, is defined in a somewhat unique fashion. It includes not only the normal cost of carrying out the activity but also includes a specific term representing a "normal" profit for the operator. This means, then, that location rents can be viewed as a potential "excess" profit for the entrepreneur.

Since equation (1) is linear and continuous, it is easily represented in a graphic form. In Figure 1, a bid rent curve for a specific activity has been plotted for parcels of land located at successively increasing distances from the market center

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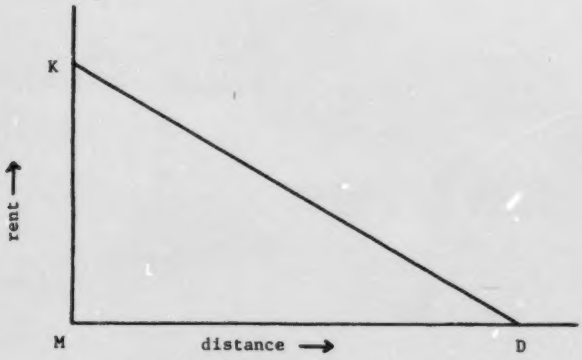

Figure 1. The Bid Rent Curve for a Single Activity

at M. The rent K is the net return derived from a parcel located at the market place and is equal to YP – YC since transport costs at that location are zero. The distance MD represents the maximum distance at which a parcel can economically engage in the activity. For distances greater than MD either a subsidy must be provided or it must be assumed that the operator is not behaving in an economically rational fashion. The slope of the bid rent curve is obviously equal to the unit transfer cost in the system and becomes increasingly steep as unit transfer costs increase. Figure 2

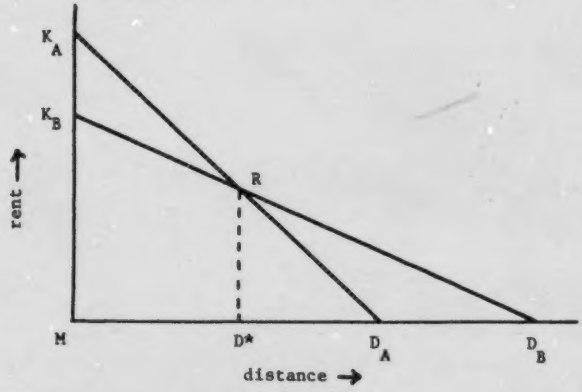

Figure 2. Bid Rent Curves for Two Competing Activities

displays a competitive situation where there are two activities, A and B, whose different bid rent curves result from differences in unit market price, unit production costs, or unit transfer costs *between* the two activities. In each case, these values remain constant for the activity at any location, but they are permitted to vary between activities. As in the previous example, K_A represents the rent at the market for a parcel utilized by activity A, while K_B represents the rent at the

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market for a parcel utilized by activity B. The slopes of the two bid rent curves differ significantly reflecting higher unit transfer costs for A than for B. If there were no competition present in the system and each activity were considered singly, then D_A would represent the maximum distance at which activity A could be undertaken with $D_B (D_B > D_A)$ representing the maximum limit of cultivation for activity B. However, the two activities are in competition for use of the parcels and within the distance MD* the bid rent of activity A always exceeds that of activity B, and hence activity A will then occupy all parcels of land between the market and location D*. However at distances greater than D* activity B produces a higher bid rent than activity A and activity B will occupy those parcels of land lying at distances from the market greater than D* and less than D_B. An entrepreneur located on a parcel of land exactly D* kilometers from the market would be indifferent between the two activities since both produce identical bid rents at that point and no economic basis exists for differentiating between them.

The graphic analysis of the competitive situation shown in Figure 2 is only one-dimensional and total rent in this case is equivalent to the area under the curve $K_A RD_B$. When translated to the two-dimensional case, two rings centered at M are formed. The first, with radius MD* encloses the area of cultivation of activity A; the second, starting at distance D* and extending to radius MD_B encloses the area of cultivation of crop B (see Figure 3). The resulting spatial pattern is one which is

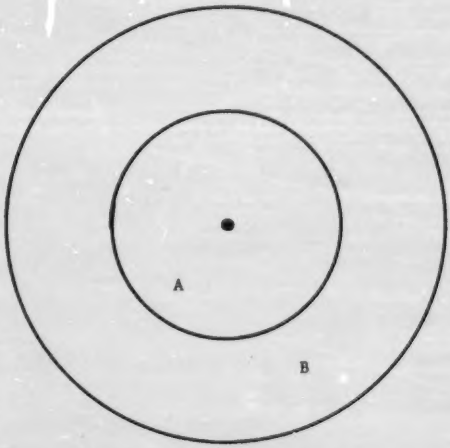

Figure 3. Simple Thünen Rings

commonly referred to as "Thünen Rings." The total rent in the two-dimensional case is then given by the volume of the solid of revolution formed by rotating $K_A RD_B$ about $K_A M$ as an axis (see Appendix A of Dunn [3] for a more detailed discussion).

A great deal has been written on the von Thünen model and for discussions of its

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many complications and extensions, see the works by Dunn [3], Isard [7], and Alonso [1]. The utility of even the simple model in explaining the observed patterns of land use has been noted by a number of researchers and much of this latter work is admirably reviewed in Chisholm [2].

Extensions of the Simple Model

The basic von Thünen model outlined above displays a number of important factors relating to agricultural production location decisions, and does so in an exceedingly simple fashion. While it may be characterized as one of the simplest models of land use, it is exceedingly fertile since it is capable of extension and modification in a variety of ways. Two of these, the expansion to multiple market centers and the introduction of space distorting transport routes will be discussed here.

Multiple Market Centers

Given the concept of land use competition, the extension of the basic von Thünen model to the case of multiple urban centers is relatively straightforward. Basically, equation (1) is recast into the following form:

$$R_{ij} = Y_iP_{ij} - Y_iC_i - Y_iT_{ij}D, (i = 1, \ldots,n; j = 1, \ldots,m) \qquad (2)$$

where: R_{ij} = rent produced by the i^{th} activity when it is oriented toward the j^{th} market center
P_{ij} = unit price for activity i at the j^{th} market center
T_{ij} = transport rate/unit/km. for movement of output of activity i to market center j
(the remaining terms are as previously defined)

Utilization of this formulation results in the establishment of multiple bid rent curves based upon the various market centers (see Figure 4). The structures are as defined in the previous example except that, in this case, an evaluation of the bid rent curves shows that at certain locations, for example, L, three "different" activities are bidding for the use of the land. At L we see positive bid rents derived from activity A oriented toward market 1 and activity B oriented toward market 1, as well as a bid rent derived from activity B oriented toward market center 2. At L, activity A oriented toward market center 1 produces the highest bid rent and hence occupies that location. However, at distances greater than M_1P we see that orientations of the two activities, A and B, toward the second market center produce higher bid rent levels than a continued orientation toward the original market center. Thus, at distance M_1L^* from the original market center, it can be seen that while activity B oriented toward market center 1 is still making a positive bid for use of the land, this bid is exceeded by those made by activity A and activity B when oriented toward the second market center. In this particular case, activity

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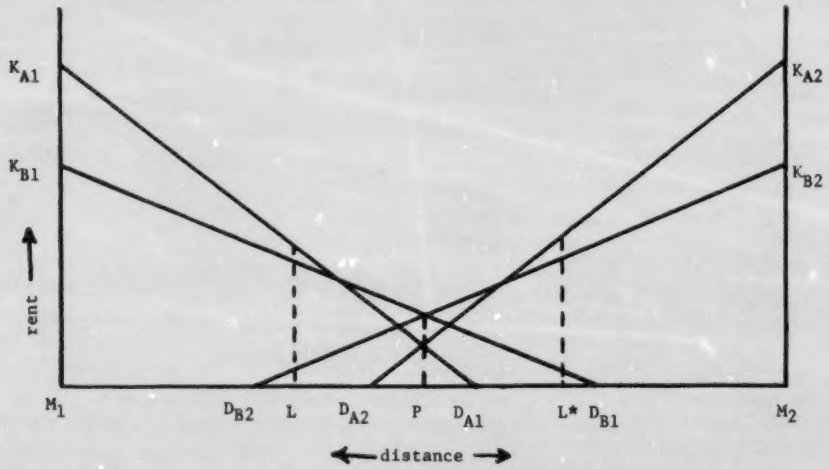

Figure 4. Bid Rent Curves for Competition Between Two Market Centers

A, with an orientation toward the second market center, occupies the location. Thus, along the line from M_1 to M_2, we see a succession of land uses, first A then B and then A again. However, within the area devoted to the cultivation of land use B there is a breaking point, P, at which the land shifts from the tributary area of the first market center to the tributary area of the second center.

An interesting problem involves the exact determination of the boundary between the tributary areas of the two centers. The boundary is clearly defined in the one-dimensional case shown in Figure 4, and can be easily inferred in the two-dimensional case where the parameter values for the two market centers are identical and an overlap between the bid rent curves exists; the boundary in this latter case will be a straight line perpendicular to the line joining the two centers. However, as one of the centers becomes "dominant," the boundary between the tributary areas of the two centers will gradually shift from a straight line to a hyperbola to a parabola and finally to a closed elliptical form around the second area with the second (smaller) market center occupying the foci of the ellipse nearest to the larger market center. Demonstration of the development of the spatial structure in these cases is usually very difficult without resort to complicated mathematical derivations or an elaborate, carefully plotted graphical display. It is, nevertheless, an interesting extension of the basic model.

System-Wide Transport Improvements

The introduction of system-wide transport improvements, such as those that might occur when a new and more efficient type of vehicle is introduced into all parts of the transportation system can be handled within the model as given in equations (1) and (2). The net effect is simply to reduce the value of T_i or T_{ij},

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which, in turn, leads to a reduction in the slope of the bid rent curves. The benefits of any system-wide improvement in transportation may be differentially distributed between activities since, for example, the introduction of a specialized and more efficient bulk carrier might favor certain commodities over others. Another example of differential impact would be the introduction of refrigerated, milk transports which would obviously influence T_i for the activity of milk production, but would have little direct impact upon the transport costs for commodities such as grain.

Route-Specific Transport Improvements

A far more interesting, and theoretically complex, case is encountered when transport improvements in the system differentially influence locations. This is typically caused in the real world by the construction or improvement of an existing transportation link. For example, a new highway linking two nodes in the system may be built or an existing road may be improved through resurfacing, thus leading to lower vehicle operating costs. Within the context of the basic von Thünen model, the introduction of specific transport routes can be viewed as a distortion of the uniform plain since unit transfer costs over the improved routes will generally be lower than transfer costs over the remainder of the area. Within the context of equation (1), this change can be handled in one of two ways: through variations in the values of the T_i depending upon the type of route over which the travel takes place or, somewhat more easily, by assuming that variations occur in D itself. This latter approach arises out of a substitution of the notion of *effective distance* for that of airline distance which was previously utilized in the model. Effective distance is defined as follows: let D_c be the minimum distance from the cell to the highway, D_t the minimum distance from the market center to the highway, and D_i the distance travelled along the highway. Then the effective distance D is given by the formula:

$$D_E = D_c + \alpha D_i + D_t \qquad (3)$$

with α in this case representing the ratio of on-highway to off-highway movement charges within the range $0 < \alpha \leq 1$. That is, for an α value of 0.5 travelling a unit distance along the highway would cost exactly half as much as travelling the same distance off the highway. The use of α as a scaling factor in the equation for effective distance compensates for the real differences in unit movement costs over the different routes. This proves to be particularly useful when the definition of effective distance is expanded to include travel over a potential system of routes:

$$D_E = D_c + \alpha_1 D_1 + \alpha_2 D_2 + \ldots + \alpha_n D_n + D_t \qquad (4)$$

where there are a series of n different highway segments in the route, each of which has associated with it an unique value of α.

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The distorting effect of low cost transportation routes was noted by von Thünen in his original analysis in a discussion of the distorting effects of a river which would provide low cost transportation for agricultural commodities upon the limits of the area under cultivation. Derivation of the geometric impact of highway improvement upon land use patterns has been undertaken by several authors, but the discussion that follows is adapted from that of Werner [20]. Werner was concerned with the distortion of the shape of the hinterland area that occurred after a new transportation route had been constructed. He defined hinterland as the area accessible from a given point with a specific level of transportation effort, where effort may be measured in terms of energy consumption, mileage, time or other criteria. The analysis assumes as given the isotropic transport plain, a point P corresponding to a market center and a straight transportation route running through the area with a cost per unit flow per kilometer of a_1 on the road and a_2 off the road. This basic situation is illustrated in Figure 5.

In Figure 5, for convenience, the new transportation route is assumed to be identical with the x-axis and P is a point on the y-axis with coordinates (0,b). The situation as shown is a symmetric one so that the analysis need only be completed for points lying to the right of the y-axis. The minimum cost connection from an arbitrary point Q_2 located sufficiently far from P and lying off the transportation route is given by a direct movement from Q_2 towards the road entering with an angle equal to arc cos a_2/a_1, then along the road itself to a point R, and then directly to point P. The angle at which the minimum cost path leaves the road is again equal to arc cos a_2/a_1.

Werner demonstrates in his analysis that the half-space under consideration can be divided into three regions, which are labeled I, II, and III in Figure 5. Within region I all points have a minimum effective cost path which consists of a direct

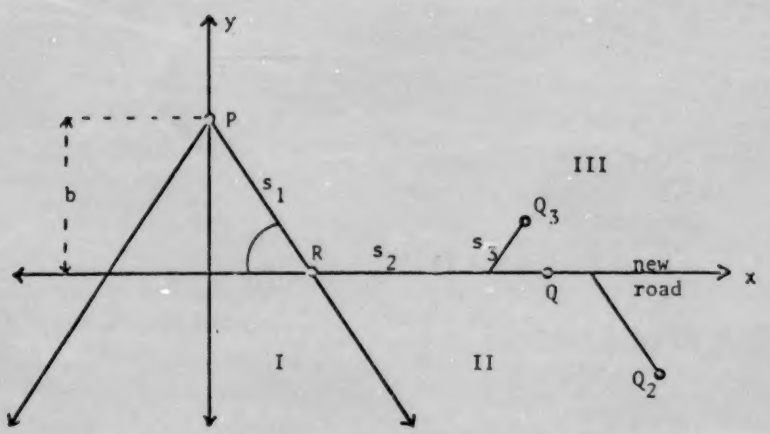

Figure 5. Determination of the Sphere of Influence of a Transport Route

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movement to point P with no movement over the road. For all points in region II, such as the arbitrary point Q_2, all minimum cost connections involve travel over the road in the fashion outlined above. The situation in region III is more complicated since for points arbitrarily close to the road, minimum effective cost paths will involve a combination of direct travel and travel over the road. For points much further from the road, direct travel will be more efficient. The boundary separating the two parts of region III, is shown to be a parabola with the point P lying in one of its foci. The resulting situation is summarized in Figure 6 which displays the areas of access via the new road versus the areas which retain direct access to point P. The shaded portion in Figure 6 represents those points in the hinterland of P that

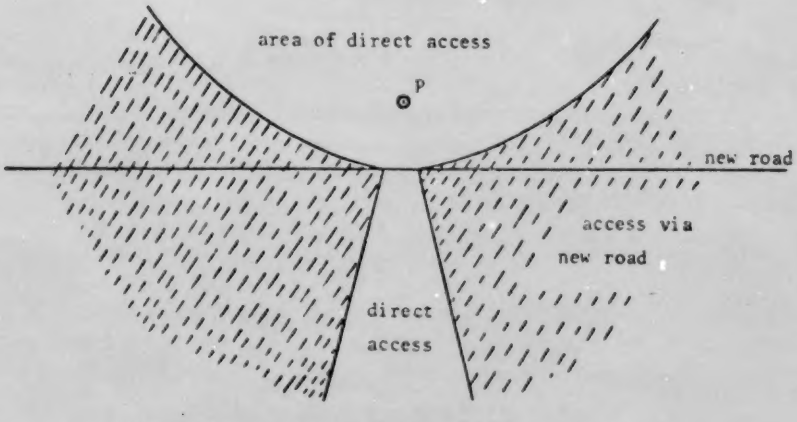

Figure 6. The Sphere of Influence of a Transport Route
Source: Werner [20]

have had their distance relationship changed by the introduction of the new transport facility, while points lying within the area of direct access retain the same distance relationships as before. For those points in the shaded area, the effective distance has been reduced by the introduction of the highway and this means that they are, in a purely economic sense, closer to P than they were prior to the introduction of the highway. By this transformation the areas of cultivation will be extended along the road, and in the areas immediately adjacent to it, in the fashion shown in Figure 7 which displays a simple Thünen ring structure for both the before and after cases. Werner goes on to show how the patterns of changed access are influenced when a variety of pre-existing transport networks are assumed and the interested reader is referred to his original exposition for further details [20].

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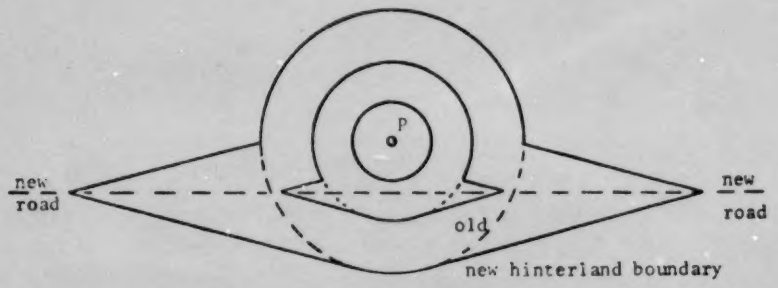

Figure 7. Ring Distortion Produced by a Transport Route
Source: Werner [20]

Summary

Material presented in this chapter has provided a summary of basic aspects of the von Thünen model and some of its more direct extensions. The reader interested in a more detailed exploration of these problems is referred to the works by Alonso [1], Chisholm [2], Dunn [3], Isard [7] and Lösch [9].

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CHAPTER III

THE LANDUSE PROGRAM

The objectives in using computer programs such as the one discussed here are set forth in the article by Huke, Fielding and Rushton [6], and in the report of the Engineering Education Project of the University of Michigan [17]. The selection of this specific process model was based upon several factors:

1) the von Thünen model is perhaps the simplest generative model for spatial patterns of land use, but is rich enough to permit a number of interesting extensions,
2) the basic model is widely known and is discussed in most economic geography courses, and
3) although the model is simple in structure, a number of operational difficulties frequently arise among students in visualizing the changes in spatial structure resulting from parameter shifts in the model.

The program was developed to provide a means whereby the student could develop a stronger feeling for the relationship between the abstract model and the spatial structure which it represents through manipulation of selected portions of the model and observation of the subsequent impact upon the spatial structure of land uses. The conventional "blackboard" approach utilizing one-dimensional cross-sections (such as those in Figures 1, 2 and 4) has not been proven to be an effective solution to this problem. Secondary development objectives included a desire to acquaint the student with the complex spatial structures that can arise out of even simple linear models (e.g., case V in the following chapter), and to provide a large group of undergraduates with an introduction to the use of the high-speed, digital computer as an analysis tool.

Program Structure

The program presented here has been designed with flexibility of use in mind. It has the capability of handling exercises ranging from those that might be appropriate for an introductory course emphasizing simple concepts to those suitable for advanced courses dealing with more complex problems. Examples of the former include generation of simple Thünen rings and the demonstration of the development of a competitive boundary between two market centers. The latter could involve any of the many complex cases of transport improvement and development. In all cases, the model relies upon the basic von Thünen model for

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evaluation of competition among land uses. Competing market centers and crops are readily handled within this framework, and one or more distance distorting transport routes can be introduced through the concept of effective distance discussed in the previous chapter.

The program assumes the existence of an unbounded, isotropic plain upon which an arbitrary (x, y) coordinate system has been established. It then isolates a rectangular subregion from the plain and proceeds to develop the pattern of land use according to the basic rent equation. Unless otherwise instructed, the program assumes that the rectangular subregion is one whose lower left hand corner corresponds to the zero points of the coordinate system. For pragmatic reasons, related to both ease of computation and ease of output, the program assumes that this rectangular area is divided into a series of small areal units which form the basis for all computations. There are 110 of these units along the horizontal axis and 90 of the units along the vertical or y-axis, producing a total of slightly under 10,000 unit areas. All coordinates which locate features on the plain, such as market centers, are specified as integer numbers in a read right-and-up coordinate system. These integer numbers correspond to cell numbers. For example, the coordinates of a market center located approximately in the center of the rectangular region would be given as $x = 55$ and $y = 45$. Within the unbounded plain, the student is permitted to locate up to a maximum of ten market centers through the simple process of specifying their x and y coordinates. However, only those towns lying within the rectangular area defined by $1 \leqslant x \leqslant 110$ and $1 \leqslant y \leqslant 90$ will appear on the output maps.

The student also specifies a series of parameters which define up to twelve abstract crops, with each crop specified in terms of the following parameters:

1) Yield per unit area (assumed to remain constant for that crop over the entire plain);
2) Unit price at each of the market centers;
3) Unit cost of production (assumed also to be invariant over the plain);
4) Unit cost of transport per unit distance (permitted to vary between market centers and between crops).

With this information in hand, the program proceeds to evaluate the rent equation for each unit area in turn beginning with the unit in the upper left hand corner. The distance from this unit to each of the defined market centers is calculated and the rent, according to the basic rent equation, that would be derived at this parcel from each crop and market center combination is obtained. For example, in a system that had two market centers and two crops defined, each unit area would have four possible bid rents based upon: crop A at market center 1, crop B at market center 1, crop A at market center 2 and crop B at market center 2. From this vector of four bid rent values, the program selects the maximum, and thus identifies the particular land use which is assigned to the parcel and determines the assignment of the parcel to a specific tributary area. If all bid rents at that location are negative, then the use assigned is "idle" and the parcel is not assigned

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to the tributary area of any urban center. For positive bid rents, the maximum value is also stored so that subsequent summaries of total rents and total areas under cultivation can be provided by crop and by crop-market center combinations.

Transport routes are defined by the simple expedient of providing the x and y coordinates of their points of origin and termination together with a value for α, the ratio of on-highway to off-highway movement charges. Program operation proceeds as described before except that the minimum effective distance is established for the computational cell prior to evaluation of the rent equation. The information on minimum effective distance, when compared with direct access distances, permits definition of the sphere of influence of the transportation route.

Subroutines

The program is written entirely in FORTRAN IV and consists of a main routine and two specialized subroutines. The main routine, LANDUSE, is responsible for all input and computational phases. The only exception occurs when highways are present and the subroutine PROJCT is called to determine the shortest distance between the analysis cell under consideration and a specific highway. It will be recalled that Werner [20] demonstrated that entry into the transport route should take place at an angle which is a function of the ratio of the two costs. PROJCT, for reasons of computational simplicity, assumes that entry always takes place at 90 degrees. This introduces some distortion, but it is felt that this can be safely disregarded in this particular case.

The subroutine REGION is responsible for all map output. It is designed to store and output up to three one-page maps using the smallest possible amount of core memory. In order to fall into the most favorable level of the priority system, the program is written to load and go using only 14,000 words of core. Storage of the three 54 x 110 maps would normally require nearly 18,000 words of computer memory, but REGION reduces this storage requirement to under 1,700 words through the use of masking statements. The amount of storage required by REGION is dependent upon the computer word length and since word length for the CDC 6000 series machines is significantly greater than for comparable computers, such as the IBM 360, the CDC version of REGION will not operate on other machines. Versions of REGION have been prepared, however, for use on the IBM 360 as well as on CDC 3000 series machines, both of which have different word lengths than the CDC 6000 series. These modified routines produce output maps of slightly different sizes than those described here (the 110 units in the x-dimension of the analysis area represents eleven CDC words each holding ten characters), but the general structure is identical.

Production of maps on the high-speed printer requires that all output be scaled by a factor of 3/5 to produce identical vertical and horizontal scales. This results from the size of the characters on the print chain (10 per inch) and the spacing between lines (6 per inch). This is why LANDUSE uses a 90 x 110 analysis region and produces 54 x 110 maps. If this scaling were not done, the Thünen rings would be significantly distorted.

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Program Limits

The program allows maxima of ten market centers, twelve abstract crops and nine transport routes. The number of computations required in the maximum case can be quite large. For example, in a problem with ten market centers and twelve crops, the program must evaluate 120 rent values for each of nearly 10,000 cells. The problem of determining patterns of land use in a system involving a relatively large number of market centers and crops is not nearly as severe, however, as the case where there are a large number of transportation routes with multiple intersections. Since each transportation route is permitted to have an individual value of α the determination of the minimum effective distance becomes quite complex. It is possible, therefore, within the defined maxima of the program to establish problems which cannot be economically solved even with a large high-speed computer. These rather high limits have been established to provide the program with the maximum amount of flexibility and not with the view that all will be reached at the same time. From a pragmatic standpoint, it is desirable to have a lower set of limits for student use. Within the program, these lower limits are established at four market centers, four crops and two highways and this is the configuration which is utilized in the normal classroom situation. Access to the larger capabilities of the program may be obtained by punching a single decoding "password" on one of the problem control cards. If this password is absent, then the lower set of maximas are in operation; if present, access is permitted to the full capabilities of the program.

Data Input

Data input to the program takes place via a sequence of control cards, the first of which is a general problem control card specifying the number of market centers, the number of crops, the number of highways and the number of re-scale runs that are to be made. This card also carries basic title information which is reproduced to identify the output, as well as the password if one is entered. The re-scale option is discussed in detail later, but basically a problem may be re-scaled through the specification of a new origin and a new scale factor for the map. If a problem is to be re-scaled, an indication of intent must be given on the problem control card. Following the problem control card, one or more data cards giving the market center coordinates are read and are followed by a third group of cards containing information on the desired scale of the map (given in terms of the number of distance units per inch) as well as yield levels for each of the crops. The fourth group of cards is called crop parameter cards, and specifies for each crop and market combination: the unit market price, the unit production cost, and the unit transportation cost per unit of distance. If transportation routes are specified in the problem, then a fifth group of cards follows specifying the starting and ending point of each transportation route as well as its associated α value. If the problem is to be re-scaled one or more times, then the final group of cards consists of re-scale cards specifying x and y coordinates of the new origin as well as the new distance

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scale factor. Any number of problems can be run in sequence by repeating the above deck structure.

Detailed instructions on the preparation of input cards are given in Appendix A.

Program Output

The output of the program consists of a series of maps as well as basic summary statistics. The first output stage consists of an echo check of data inputs and repeats, in tabular form, the information pertaining to market centers, crops and highways that has been read from the data cards (see Figures 8 and 9). This permits the student to check quickly for errors in his control cards. Following the echo check, from one to four maps are produced depending upon the problem control card parameters. The first map is always a general location map which displays the location of all market centers and highways in the problem (see Figure 10). All maps are identical in format with market center locations shown as "X" 's, and all carry small crosses at the corners of the rectangular analysis area to serve as registration points should the student desire to overlay one or more maps for comparative purposes. If highways have been defined in the system, then the second map is one showing the location of the market centers as well as those cells which fall within the "sphere of influence" of each of the highways (see Figure 11).

Highways are identified by the program by reference to the sequence in which the highway control cards are read. That is, the first card is identified by the program as being associated with highway number 1, the second card with highway number 2, and so forth. A cell whose effective distance to any of the market centers is reduced through the existence of highway 1 has a "1" printed in it. Similarly, any cell which is influenced by highway 2 has a "2" printed in it, etc. Those cells through which direct access still represents the minimum effective distance are left blank. Thus, the area of the map which is filled with "1" 's represents the sphere of influence of highway 1, the area filled with "2" 's represents the sphere of influence of highway 2, and so forth.

```
COMMISSION ON COLLEGE GEOGRAPHY * LANDUSE EXAMPLE

*** CASE  1 ***


THIS PROBLEM SPECIFIES

        3 MARKET CENTERS.
        2 CROPS. AND
        3 HIGHWAYS.
```

Figure 8. Output Sample–Echo Check, 1

MARKET CENTER LOCATIONS

MARKET CENTER	X COORDINATE	Y COORDINATE
1	30	60
2	40	20
3	80	40

CROP YIELDS

CROP A	30.0000 UNITS
CROP B	30.0000 UNITS

MARKET/CROP PARAMETERS

MARKET CENTER	CROP	MARKET PRICE	PRODUCTION COST	TRANSPORTATION COST
1	A	35.00000	5.000000	1.500000
1	B	30.00000	5.000000	1.000000
2	A	35.00000	5.000000	1.500000
2	B	30.00000	5.000000	1.000000
3	A	35.00000	5.000000	1.500000
3	B	30.00000	5.000000	1.000000

HIGHWAY DATA

HIGHWAY	STARTING POINT X COORDINATE	STARTING POINT Y COORDINATE	ENDING POINT X COORDINATE	ENDING POINT Y COORDINATE	ALPHA
1	80	40	30	60	.5000000
2	40	20	80	40	.5000000
3	30	60	40	20	.5000000

Figure 9. Output Sample–Echo Check, 2

Figure 10. Output Sample–Location of Market Centers and Highways

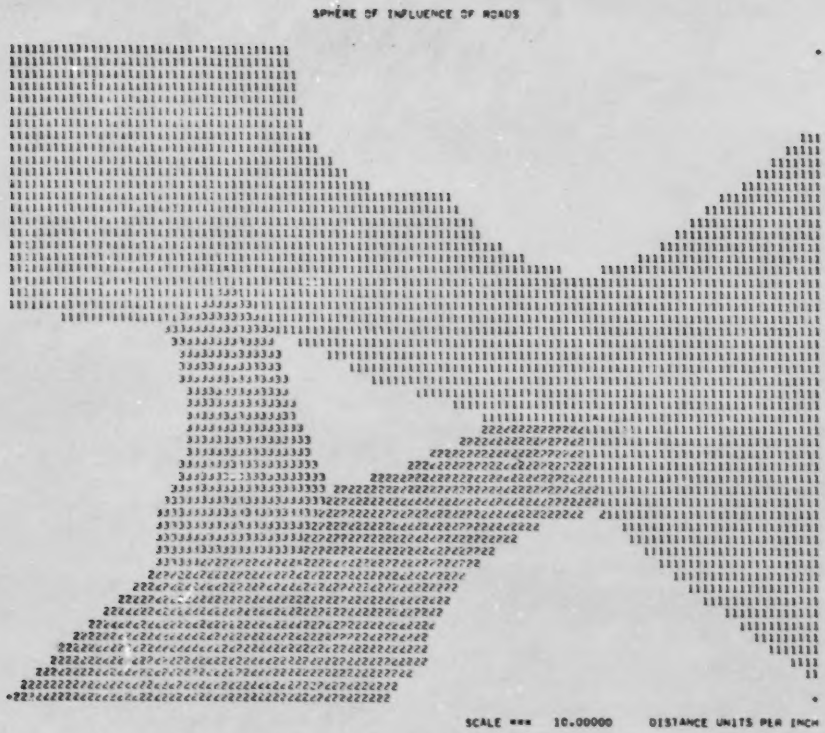

Figure 11. Output Sample–Sphere of Influence of Highway

The next map produced is a general land use map (see Figure 12). This map shows the location of each of the market centers as well as the pattern of land use. The first control card read is associated with crop A, the second with B, etc. Any cell for which crop A has the highest bid rent has an A printed in it on this map, any cell with crop B having the highest bid rent has a B printed in it, etc. Cells for which all bid rents are negative are left blank. For those cells for which two or more bid rents are identical an "=" sign is printed indicating that a tie exists between two or more land uses. The last map identifies the tributary areas of each market center (see Figure 13). The first set of coordinates read is assumed to define market center 1, the second set of coordinates market center 2, etc. A cell is assigned to center 1 if the highest bid rent for that cell is one which is associated with sales at market center 1, it is assigned to center 2 if the sales are associated with market center 2, etc. Ties are again identified by printing of an "=" sign in the cell.

The final output section consists of a set of summary statistics relating to rent and area under cultivation for each market center and crop combination (see Figure 14). Total rent and total area under cultivation are also given for each crop and the

Figure 12. Output Sample–Land Use

total area with zero rent level, that is, idle land, is also presented. The summary statistics are useful in providing quantitative measures of impacts due to parametric changes.

Introduction of Transportation Routes

Transportation routes are defined within the study area through specification of the coordinates of their points of origin and termination as well as the associated α value. The α value represents the ratio of on-highway to off-highway movement charges and an α value of one implies that these are identical. Thus, an α value of 0.5 implies that travel on the transportation route is only one-half as costly as travel off the highway. Based upon empirical investigations of vehicle operating costs, it is possible to select α values which are at least roughly in accordance with reality. A number of studies have examined the effect of transport improvements on vehicle operating costs and if the assumption is made that an α value of 1 is roughly equivalent to the crudest of dirt roads, then relative values of α may be established

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Figure 13. Output Sample–Tributary Areas

for other common road surfaces as well as for different types of vehicles. Table 1 presents some suggested values for α which are based upon empirical investigations. These values are only suggestive since many other factors influence the level of operating costs. However the fact that they are based upon "real-world" data tends to make them more viable in the mind of the student.

The sphere of influence of a highway is defined as the set of all cells for which the average effective distance from the cell to *all* N market centers is less than the average airline distance to the towns, or the average effective distance to the towns using all other highways. A cell which falls within the sphere of influence of a given highway is identified on the map with that highway's number, while those cells whose minimum average distance is the average airline distance are left blank. If the average effective distances are equal for any two highways with respect to a given cell, an "=" sign is then printed in the cell.

A transport route may be of any length and may run in any direction, but care

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SUMMARY STATISTICS

MARKET CENTER	CROP	RENT	AREA
1	A	256310.4	428.3333
1	B	331940.3	1523.333
2	A	251333.1	410.6667
2	B	310792.9	1300.000
3	A	249219.5	413.3333
3	B	347813.5	1583.333

TOTALS

CROP	TOTAL RENT	TOTAL AREA
A	756863.0	1258.333
B	990586.7	4406.667

AREA WITH ZERO RENT LEVEL • 4231.667

Figure 14. Output Sample–Summary Statistics

must be taken that, either through initial specification or subsequent re-scaling, the effective length of the highway is not reduced to zero. If this should occur then an error message is issued and the program terminates.

Changes in Origin and Scale

All points on the isotropic plain are assumed to be specified in terms of integer coordinates so that a unit increment in either the horizontal or vertical direction corresponds to a distance of one-tenth of an inch on the printed map. The factor SCALE is a non-negative, floating point number which assigns a physical distance to this unit increment. The physical distance may be either abstractly defined or in feet, miles, kilometers, etc., and ten times the value of SCALE is the distance per unit of the printed output maps. The distance scale which is in effect for a particular problem is printed at the bottom of each map. In order to obtain maps covering different regions within the plain, the coordinates of the defined market centers and highways must be modified and/or the value of SCALE must be changed leaving the remaining data the same. In this case, physical distances must be regarded as invariant, that is modifications of the value of SCALE or shifting of the origin must necessarily cause a consistent modification of the originally specified integer coordinates which will preserve the "actual" distances in a spatial system. Appendix A contains information on how these scale shifts and shifts of the origin are computed by the program.

The program contains an option which will automatically re-scale any specified

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Table 1

OPERATING COSTS AND ALPHA VALUES FOR ROAD SURFACE AND EQUIPMENT CLASSES IN A DEVELOPING NATION*

Equipment Class	Road Surface		
	Earth	Gravel	Paved
Small passenger car	3.26 (1.0)	2.55 (0.78)	1.98 (0.61)
Large passenger car	5.32 (1.0)	4.13 (0.78)	3.23 (0.61)
1-ton truck	6.79 (1.0)	4.78 (0.70)	3.56 (0.52)
3.5-ton truck	11.79 (1.0)	7.47 (0.63)	5.13 (0.44)
15-ton tractor semi-trailer	20.53 (1.0)	12.19 (0.59)	7.92 (0.38)

*Figures are cents/vehicle-kilometer; bracketed numbers are alpha values assuming earth surface to be equivalent to $\alpha = 1.0$

Source: Adapted from figures given in United Nations. *Transport Modes and Technologies for Development*, 1970.

problem. A problem which is specified by a data set immediately following a problem control card is called the reference case. Each re-scale data card which follows a reference case may contain the coordinates of a new origin as well as a new scale factor. The coordinates of a new origin on the re-scale card are assumed to be given in terms of the original coordinate system. That is, the system may be viewed by the student as taking the original rectangular analysis area (which the program assumes to be located with its lower left hand corner at the zero point of the coordinate system) and moving its lower left hand corner to the new coordinates specified on the re-scale card. If a scale change is also specified, the relative size of the region and the analysis areas will be changed as well. The original coordinates of the market centers and highways, as specified in the reference case, are saved and new coordinates are computed relative to this reference problem for each subsequent re-scaling. Changes of origin may or may not be accompanied by

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subsequent changes in scale. In many complex problems, it has been found that changes in origin together with simultaneous changes in scale produce useful results in terms of clarifying the analysis. For example, a complex case may be developed and the student may desire to examine in greater detail some limited portion of it. He may then request that the scale of the map be shifted to provide more detail and that the origin be translated to such a location that the area of greatest interest is centered in the new map.

In the case of re-scale operations, the number of analysis cells defined in the rectangular region remains the same while their area is effectively changed. In the present version of the program, this means that the summary statistics in the reference case and the re-scaled case will not be comparable. This problem will be eliminated in a future version of the program.

Using LANDUSE

The LANDUSE program was developed at the Department of Geography, Northwestern University, over a three year period. The program was initially used in an upper division course in economic geography having an enrollment of about 25 students, most of whom were graduate students from other disciplines. Problems were assigned on an individual basis and were fairly complex in their structure since the student group possessed a substantial background in related areas such as transportation engineering. The use of the program with this small group of mature students posed a few problems.

During the next year, with the cooperation of Dr. Ian Hamilton (Department of Geography, London School of Economics) who was a visiting professor at that time, the use of the program was extended to a larger, lower division course in introductory economic geography. This course had a registration of about 70 students and because of the larger class size, the students were "teamed" in groups of two or three in order to reduce operating costs and the load on rather limited keypunch facilities. Teaming in groups greater than three did not prove successful because of the increasing remoteness of the individual student from the exercise.

At the present time, the program is used in both the lower division and upper division economic geography courses. The types of problems assigned differ significantly with the more complex problems in the upper division course reflecting the more substantial background of these students, and their specific interest in questions of transportation and its relationship to the spatial structure of land use.

General experience with the program indicates that it has a high level of student acceptance and that it does increase their level of knowledge in the desired areas.

Necessary Student Background

Aside from a theoretical grounding in the notion of economic rents and location rents, and in the general structure of the simple von Thünen model, the student must know how to prepare the data cards for the program, how to submit the

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program to the computer and how to retrieve his output. In most cases, particularly when dealing with lower division students, the instructor cannot assume student familiarity with either computers or the operation of the keypunch. Our experience has shown that basic keypunch instruction can be given in about 15 or 20 minutes and that an introduction to the program, card layout and computer center operation takes about an hour. In many universities, basic keypunch instruction is provided by the computer center through either direct demonstration or by student access to video recordings. A sample of the keypunch reference material given to Northwestern students can be seen in Appendix C.

The first exercise which is normally assigned at both class levels is a "set piece" wherein all parameter values are given. This is designed to test the student's familiarity with card preparation and system operation. Case I in the following chapter is usually used for this purpose.

Operating Costs

The cost of operating the program is a function of the charge level established by the local computer center, as well as of the number and complexity of the problems which are assigned by the instructor. In the introductory course at Northwestern, where only a few simple problems are assigned to teams of students, operating costs are approximately $14.00 to $15.00 per student. More complex problems, although not a greater number, are assigned in the upper division course on an individual basis and here the cost per student rises to between $50.00 and $70.00. In many cases these charges, particularly those for the lower division class, reflect a level which is related only to the number of job submissions made, since at Northwestern a minimum charge of $1.00 per job is set by the computing center. In dealing with simple problems, one of the major factors influencing total class cost is the number of submissions per student. This can be minimized by making use of the provision within the program for stacking problems so that a number of different cases can be run on the same submission. When used, this tends to reduce significantly the cost per student.

The cost per student is also increased when students substitute repetitive tests on the computer for thinking about the operation of the model. Prior to being given the exercises, the students are instructed to produce trial solutions utilizing standard graphic methods, such as those shown in Figures 2 and 4. However, the student finds that it is less work to change merely one or two numbers in his input deck and resubmit the problem. This substantially increases the number of runs and the total cost. Some computer installations have monitor routines available that will check the number of submissions made by an individual student and will either prohibit access after a certain number of tries or will call the situation to the attention of the instructor. Such a program is not available at Northwestern, but a comprehensive monitoring program is being developed which should alleviate this problem and permit the instructor to identify those students who are having difficulties with the operation of the program.

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While the dollar figures cited here refer to a $7.00/minute computer charge, it must be kept in mind that at many schools the assignment of dollar values to classroom use of the computer does not result in any actual transfer of funds. The "charge" in these cases provides only a means of allocating a fixed resource (which is paid for in the school's annual budget) among competing users. Charge policies vary widely among schools and the prosepctive user should make local inquiries.

Program Availability

Because LANDUSE is a large, complex routine which is undergoing continuing development, a listing of the source deck is not included in this technical paper. However, machine-readable versions of the current distribution version may be obtained from the Geography Program Exchange. The activities of the Exchange and methods of obtaining programs are described in Appendix B. The GPE will provide either CDC or IBM versions of the program and persons requesting machine-readable copies should specify the machine which will be used.

Persons using the program are requested to forward their comments to the author.

CHAPTER IV

SOME APPLICATIONS OF THE LANDUSE PROGRAM

The following six cases have been chosen to demonstrate the versatility and flexibility of the program. Parameter values were selected to reflect this goal. Exercises featuring more "realistic" parameters can be developed easily within the context of a particular course. The cases presented here begin with a simple situation which reproduces the basic Thünen ring structure and then proceed through sucessive complications to a complex case of transport impact combined with a demonstration of the use of the re-scale option to provide a finer grain examination of the results.

For ease of interpretation, boundaries and market center locations have been emphasized through the addition of hand inserted symbols in most illustrations in this chapter.

Case I – Simple Thünen Rings

This case demonstrates the ability of the model to replicate the formation of simple Thünen rings around a single market center. It is normally utilized as a "set piece" in order to familiarize the student with card preparation, program submission and interpretation of the output. The parameter values for generation of this case are shown in Table 2, and Figures 15 and 16 display the resulting land use pattern and market area structure.

Table 2

CASE I – PARAMETER VALUES

Market Center Locations

Market Center	X Coordinate	Y Coordinate
1	55	45

Crop Yields

Crop A	30.00 Units
Crop B	30.00 Units

Market/Crop Parameters

Market Center	Crop	Market Price	Production Cost	Transportation Cost
1	A	35.00	5.00	1.50
1	B	30.00	5.00	1.00

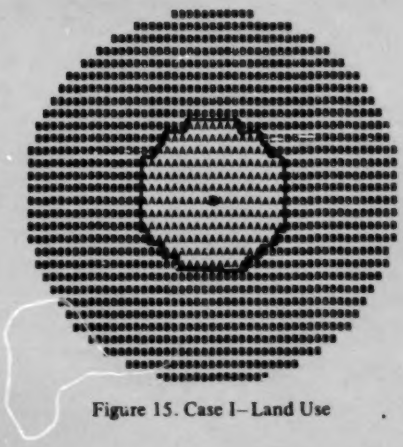

Figure 15. Case I–Land Use

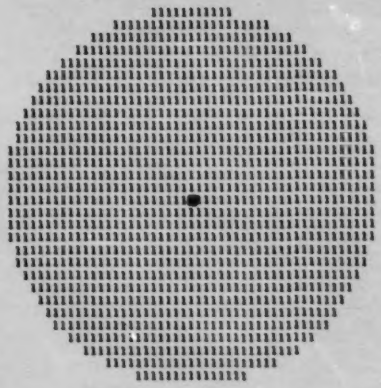

Figure 16. Case I–Tributary Area

Case II – Competition Between Market Centers

The case of competition between two market centers can be dealt with easily within the context of the program. Case II represents a somewhat arbitrary selection of parameters leading to a situation where the first center is "dominant" with respect to the second. The land use pattern which results is displayed in Figure 17. An examination of this map shows that Thünen rings develop around both centers and that land use B merges between them. A more interesting pattern is revealed when the tributary areas map, Figure 18, is examined. Here the dominance of the first center is clearly evident and the boundary between the trade areas of the two centers bends in the direction of the second center which occupies an off-center location within its trade area. Through suitable adjustment of the parameters, the boundary between the two trade areas may be bent even further to the right and in the extreme, caused to close on the far right thus embedding the trade area of center 2 entirely within the trade area of center 1. Table 3 gives the parameter values which will reproduce this case.

Table 3

CASE II – PARAMETER VALUES

Market Center Locations

Market Center	X Coordinate	Y Coordinate
1	36	45
2	74	45

Crop Yields

Crop A	30.00 Units
Crop B	30.00 Units

Market/Crop Parameters

Market Center	Crop	Market Price	Production Cost	Transportation Cost
1	A	45.00	5.00	1.00
1	B	40.00	5.00	0.75
2	A	35.00	5.00	1.50
2	B	30.00	5.00	1.00

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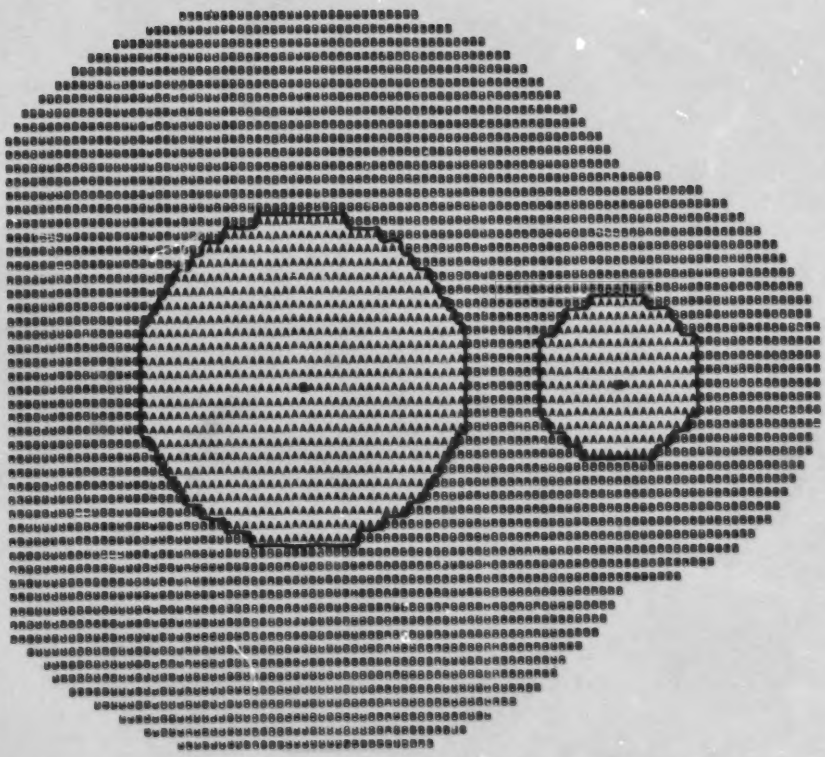

Figure 17. Case II–Land Use

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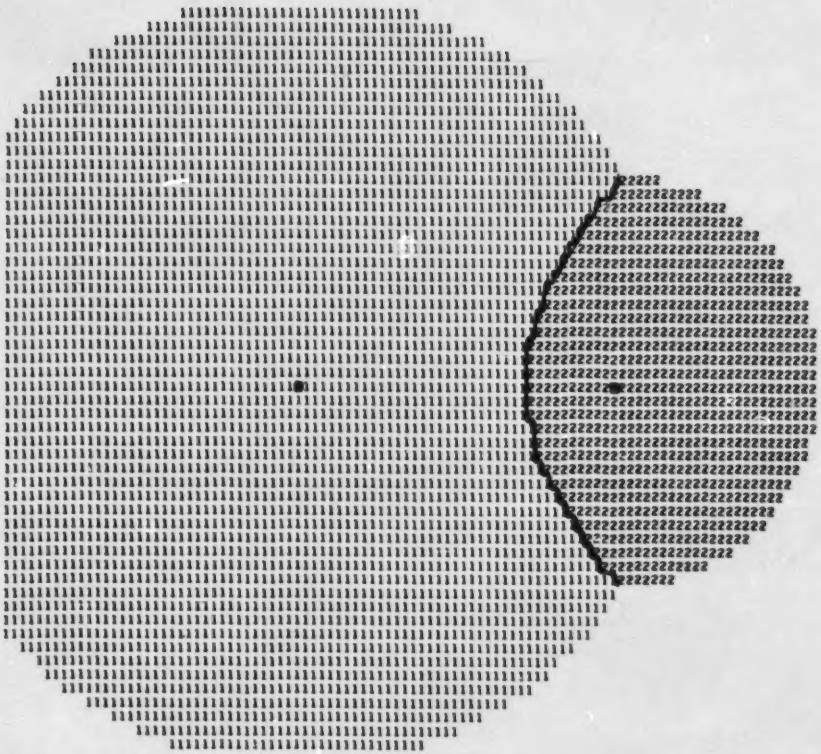

Figure 18. Case II–Tributary Areas

Case III – Transport Route Bypassing a Market Center

This case is a replication of case I with the introduction of an east-west transportation route running slightly to the south of the market center as shown in Figure 19. Figure 20 gives the sphere of influence of the transportation route with those cells containing a "1" having a minimum effective distance which involves use of the transportation route. The thin vertical line of 1's immediately below the market center results from an anomalous condition wherein crossing of the transport route is counted as use of the route. This will be removed in a future version of the program. Figure 21 demonstrates the resultant patterns of land use and should be compared directly with Figure 15. Although there is an observed extension of land use B along the transportation route, there is no impact upon the pattern of cultivation of land use A, such as one might have expected from an examination of Figure 7. The reason for the lack of distortion of the A rings can be seen through a comparison of Figures 20 and 21. Superimposition of Figure 20 over Figure 21 reveals that the sphere of influence of the highway does not extend into the A ring and hence no change is recorded for those cells. Figure 22 displays the resulting distortion of the trade area along the transport route and Table 4 gives the parameter values which will reproduce this case.

Figure 19. Case III–Market Center and Highway Location

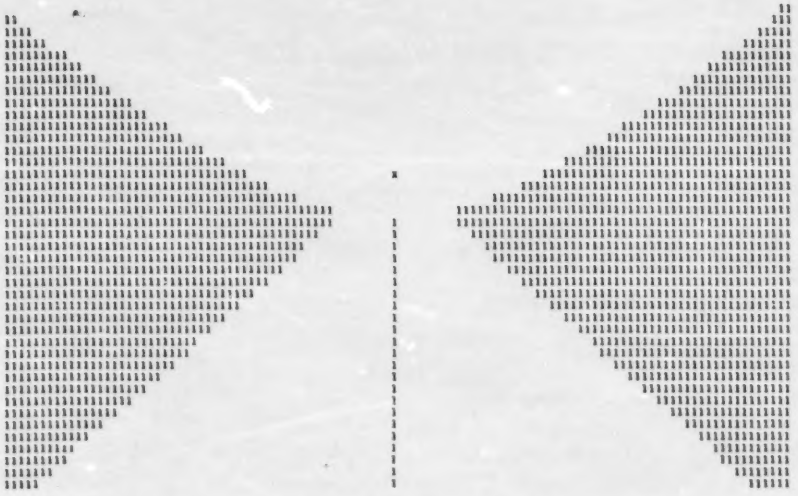

Figure 20. Case III–Sphere of Influence of Highway

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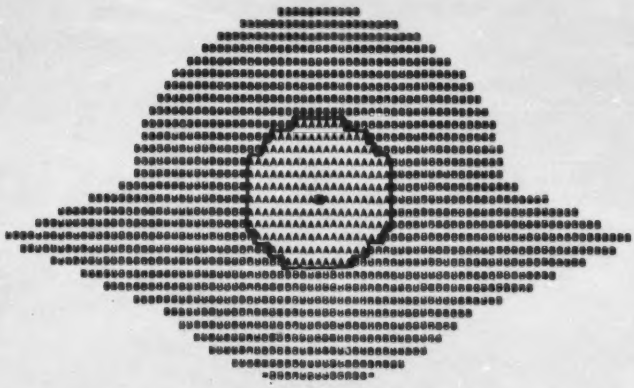

Figure 21. Case III–Land Use

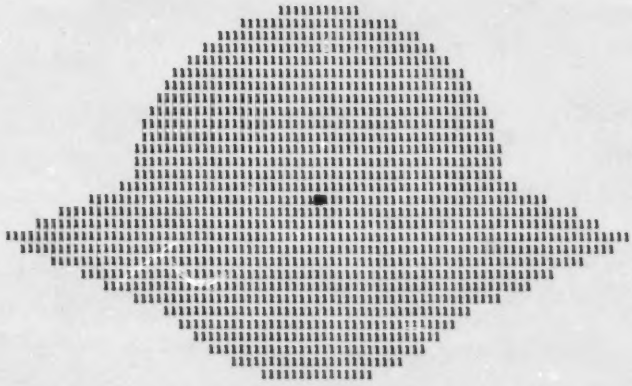

Figure 22. Case III–Tributary Area

Table 4

CASE III – PARAMETER VALUES

Market Center Locations

Market Center	X Coordinate	Y Coordinate
1	55	45

Crop Yields

Crop A	30.00 Units
Crop B	30.00 Units

Market/Crop Parameters

Market Center	Crop	Market Price	Production Cost	Transportation Cost
1	A	35.00	5.00	1.50
1	B	30.00	5.00	1.00

Highway Data

	Starting Point		Ending Point		
Highway	X Coordinate	Y Coordinate	X Coordinate	Y Coordinate	Alpha
1	1	39	108	39	0.45

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Case IV – Market Center Competition and Transport Impact

This case is a replication of case II with the addition of a transport route bypassing the two competing centers a short distance to the south. The spatial positioning of the two market centers and the transport route is shown in Figure 23. Because of the existence of two centers, a more complex pattern emerges when the sphere of influence of the road is examined (see Figure 24). The impact of the transport route produces an extension of cultivation of both crops A and B to a point where the new band of cultivation of crop A along the highway nearly joins the two centers (see Figure 25). There is, however, still a small island of B production remaining at the edge of the A–B ring around the second center. Again, many of the more interesting results of the insertion of the transportation route can be seen in the examination of Figure 26 which displays the configuration of the two market areas. Some very significant changes can be observed by comparing Figure 26 with Figure 18. The introduction of the transport route has extended the trade area of center 1 far to the east of center 2 and the lower boundary between the two trade areas has now been wrapped up and around center 2, so that its trade area has become a parabola oriented toward the northeast. The parameter inputs which replicate this case are given in Table 5.

Figure 23. Case IV–Location of Market Centers and Highway

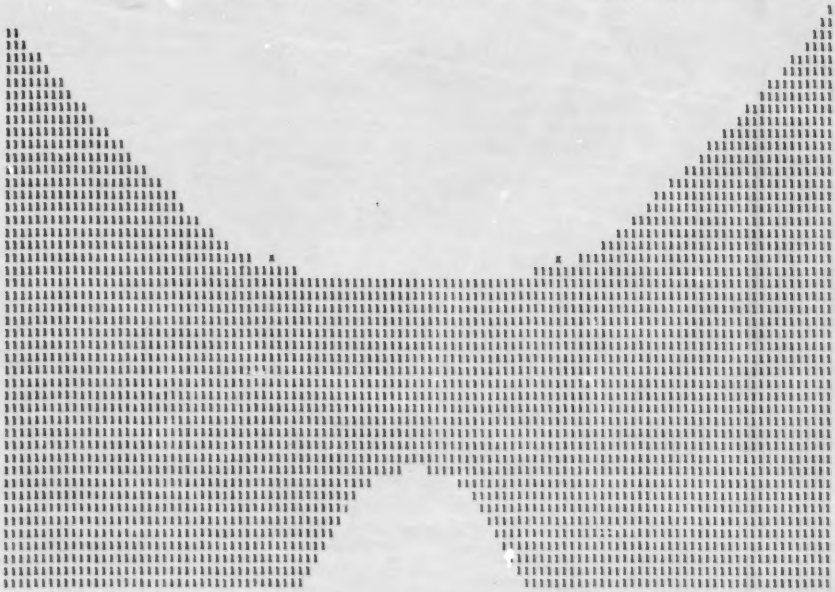

Figure 24. Case IV–Sphere of Influence of Highway

00045

Table 5

CASE IV – PARAMETER VALUES

Market Center Locations

Market Center	X Coordinate	Y Coordinate
1	36	45
2	74	45

Crop Yields

Crop A	30.00 Units
Crop B	30.00 Units

Market/Crop Parameters

Market Center	Crop	Market Price	Production Cost	Transportation Cost
1	A	45.00	5.00	1.00
1	B	40.00	5.00	0.75
2	A	35.00	5.00	1.50
2	B	30.00	5.00	1.00

Highway Data

	Starting Point		Ending Point		
Highway	X Coordinate	Y Coordinate	X Coordinate	Y Coordinate	Alpha
1	1	37	108	37	0.30

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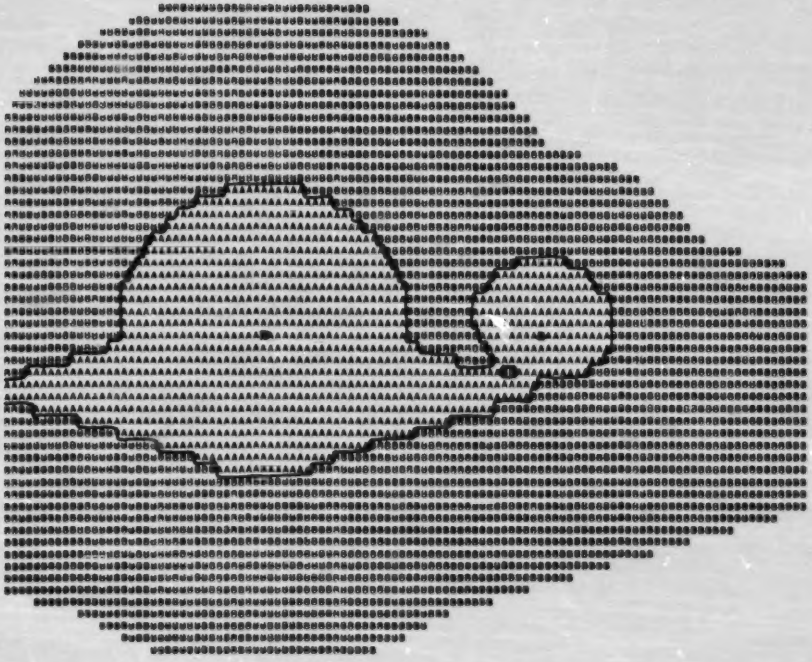

Figure 25. Case IV–Land Use

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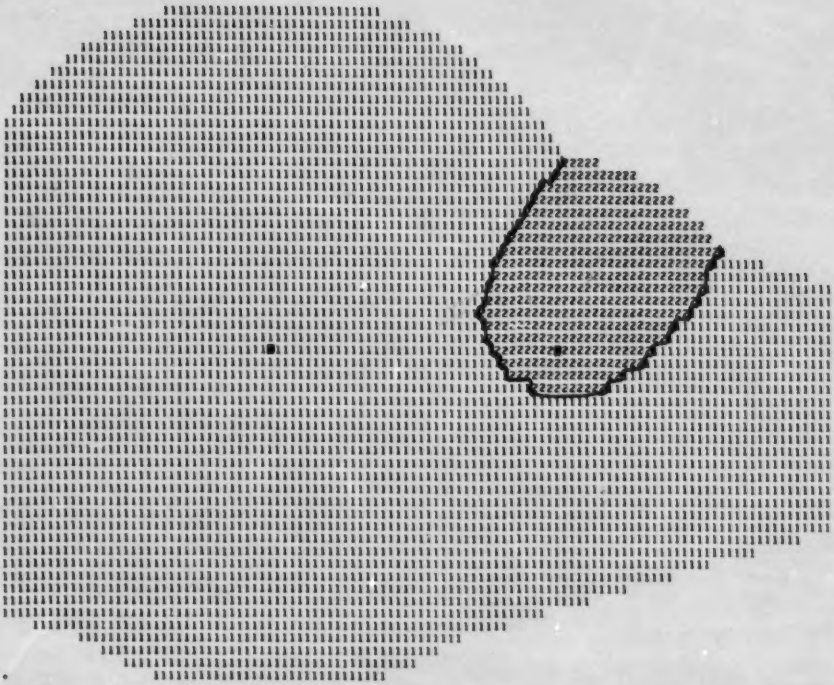

Figure 26. Case IV – Tributary Areas

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Case V – Complex Transport Impact

This case is designed to demonstrate that the application of the simple linear model can produce relatively complex spatial patterns in the presence of both competing market centers and off-center transportation routes. Figure 27 displays the spatial situation of market centers with respect to the two transport routes, and Figure 28 defines the relative spheres of influence of the two transport routes. The operation of the model produces a very complex pattern of land use, as shown in Figure 29, which nevertheless bears a resemblance to that seen in cases II and IV. Three Thünen rings form around the first market center while an incipient ring structure seems to be forming based upon the second and third market centers. The

Figure 27. Case V – Location of Market Centers and Highways

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border of cultivation is obviously distorted along each of the transport routes. Turning to Figure 30, the tributary areas map, we see that the particular parameter structure adopted here has generated a discontinuous market area for center 2. A northeast extension of the market area of center 1 occurs as a result of the effect of the second highway and divides the market area of the second center in two parts. The market area of the third center displays some of the characteristics seen in the market area of the second center in the previous case. Table 6 gives the parameter inputs for replication of this example.

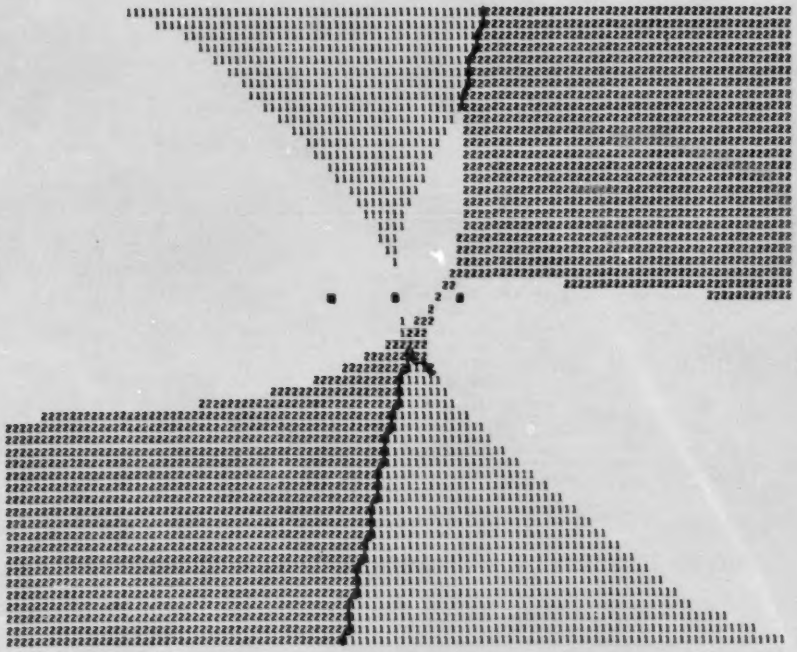

Figure 28. Case V–Spheres of Influence of Highways

00050

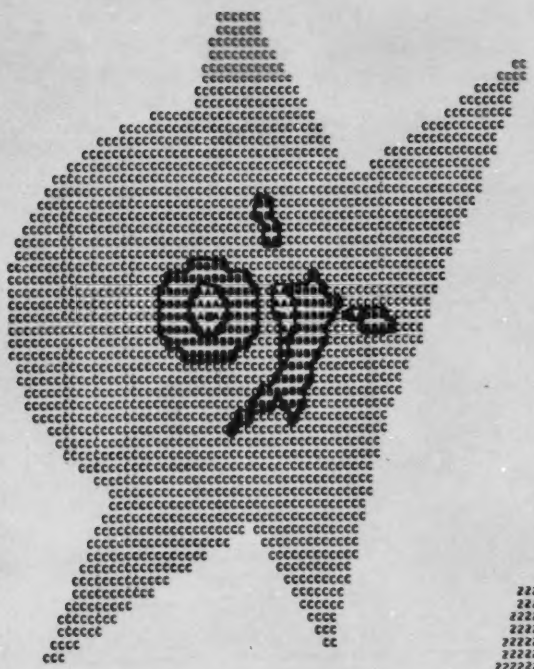

Figure 29. Case V – Land Use

Figure 30. Case V – Tributary Areas

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Table 6

CASE V – PARAMETER VALUES

Market Center Locations

Market Center	X Coordinate	Y Coordinate
1	46	50
2	55	50
3	64	50

Crop Yields

Crop A	10.00 Units
Crop B	10.00 Units
Crop C	10.00 Units

Market/Crop Parameters

Market Center	Crop	Market Price	Production Cost	Transportation Cost
1	A	47.00	19.60	1.10
1	B	47.00	19.80	1.03
1	C	47.00	20.00	1.00
2	A	39.00	19.60	1.10
2	B	39.00	19.80	1.03
2	C	39.00	20.00	1.00
3	A	31.00	19.60	1.10
3	B	31.00	19.80	1.03
3	C	31.00	20.00	1.00

Highway Data

	Starting Point		Ending Point		
Highway	X Coordinate	Y Coordinate	X Coordinate	Y Coordinate	Alpha
1	62	1	50	90	0.40
2	22	1	94	90	0.30

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Case VI – Change of Scale and Origin

This final case is included to illustrate the manner in which changes of scale and origin may be used to eliminate complex spatial patterns. Figure 29 displays a relatively complex spatial land use pattern whose interpretation is greatly hindered by the size of the printer elements. The insertion of a re-scale card at the end of the previous example produces a more detailed map of a portion of the original area. The origin was moved up and to the right, and the base scale of the map was changed from 10 units to the inch to 2.5 units to the inch, producing a fourfold enlargement of the subarea. The resultant map shows all three market centers as well as portions of the two roads, Figure 31, and the appropriate portions of the sphere of influence map, Figure 32. The re-scale operation produces, in Figure 33, a

Figure 31. Case VI–Location of Market Centers and Highways

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significantly enlarged version of a portion of the original land use map. Here the relationship between the various crops and market centers can be seen more clearly, as can the impact of the two transport routes. Figure 34 shows the market area boundaries in the subarea in a more detailed fashion than did Figure 30. Thus, the change in scale and location of the origin leads to increased ease of interpretation by the student. Table 7 shows the factors which were entered on the re-scale cards to produce this case.

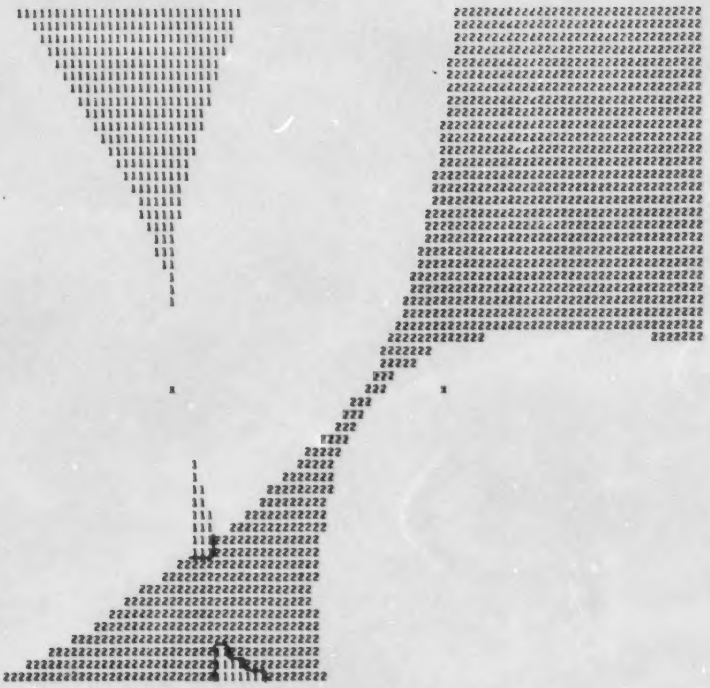

Figure 32. Case VI–Spheres of Influence of Highways

00054

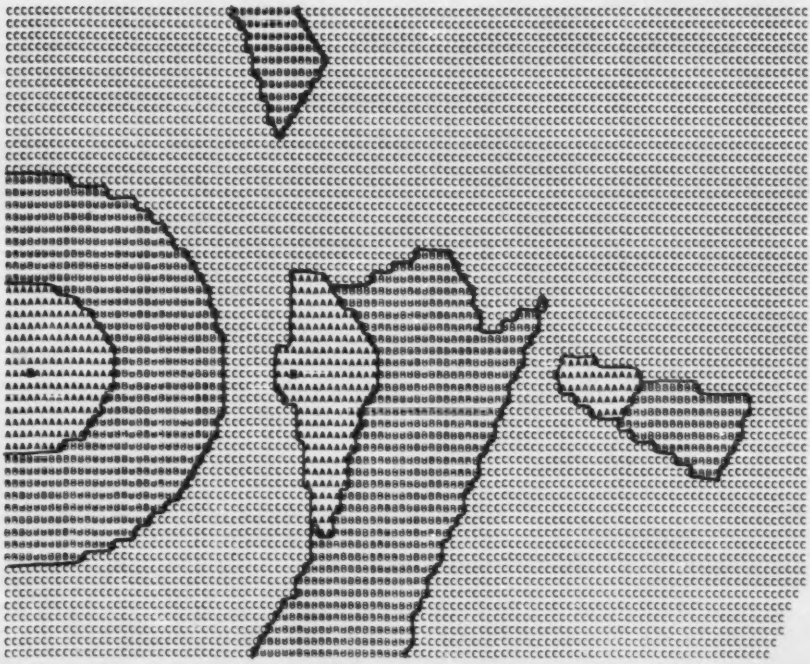

Figure 33. Case VI– Land Use

Table 7

CASE VI – RESCALE DATA

New Origin	
X Coordinate	Y Coordinate
45	40

New Distance Scale Factor
0.25

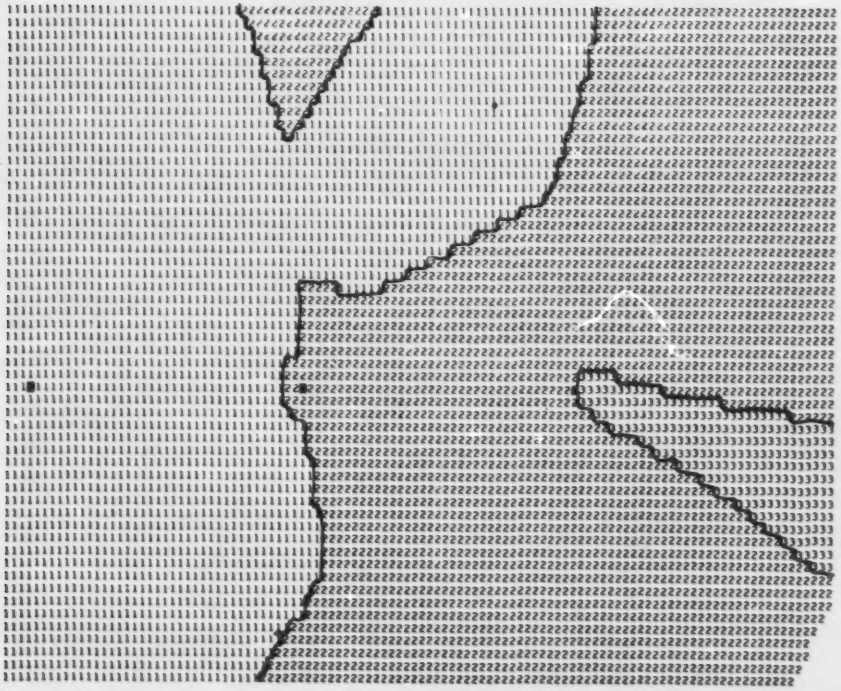

Figure 34. Case VI--Tributary Areas

Conclusion

The examples presented here demonstrate the variety of ways in which LANDUSE can provide a basis for the development of computer-based laboratory exercises for economic geography courses. The flexibility of the program permits it to be utilized in courses on nearly any level and the type of exercises developed can be tailored to any group of students.

LANDUSE is still undergoing development (e.g., it will soon be possible to study the effects of systematic, areal variations in productivity) and comments and suggestions from users are welcomed.

APPENDIX A

DETAILED OPERATING INSTRUCTIONS

Version 2.0

Department of Geography
Northwestern University

LANDUSE

Purpose: Development of land use and market area patterns according to the basic Thünen model.

Description: Within a rectangular area this program develops the pattern of land use according to the basic Thünen model: $R = Y(P - C - TD)$, where R is the economic rent, Y is the yield per unit area, P is the unit market price, C is the unit production cost, T is the unit transportation cost per unit distance and D is the distance to the market. The use producing the highest rent level is assumed to occupy the unit of land. In addition to N market centers and M crops, NROAD highways may be defined for a given problem. Crop yields (Y) are assumed constant for each crop over the total area.

In general, the addition of a highway will expand the amount of usable land by reducing the effective distance from a cell to a market center and, thereby, reducing the transportation cost. The restriction of α, the ratio of on-highway to off-highway movement charges, to $0 < \alpha < 1$ implies that the effective distance along the highway is reduced by the factor α below the same distance off the highway. As it is possible for a problem to have multiple highways, it is necessary to consider all possible paths including the direct path from a given cell to each market center and to select from these the minimum effective distance. Let $i_1, i_2, \ldots i_r$ be subscripts which identify r highways to be traveled in sequence from a cell to a market center, and assume further that this is the minimum effective distance path. Let D_C be the minimum distance from the cell to highway i_r, D_T the minimum distance from the market center to highway i_r, and $D_{i_1}, D_{i_2}, \ldots, D_{i_r}$ be the distances traveled along the r highways. Then the effective distance D is given by the formula:

$$D = D_C + \alpha_{i_1} D_{i_1} + \alpha_{i_2} D_{i_2} + \ldots + \alpha_{i_r} D_{i_r} + D_T$$

The rectangular area relevant to program computations is between 1 and 110 units horizontally and 1 and 90 units vertically. This corresponds to the printed maps which are 54 lines at 110 characters per line. There are 10 characters per inch horizontally but only 6 lines per inch vertically so that the computer output must be scaled by a factor of 3/5 to accommodate the printer and provide the same scale vertically and horizontally. All coordinates locating towns and roads are specified as arbitrary integer numbers; however, only the towns and portions of highways lying within the rectangular area defined by $1 \leq X \leq 110$ and $1 \leq Y \leq 90$ will appear on the output maps.

The program currently allows maxima of 10 market centers, 12 crops, and 9 highways. Since the minimum distance must be computed from each cell to each town, problems could be devised using these maxima which might require a month or more of computer time. The lower set of maxima of 4 market centers, 4 crops, and 2 highways has been included in the program for student usage. Access to the expanded set of limits is provided by punching a decoding "password" of up to 10 characters in columns 71 - 80 of the problem control card.

Data input to the program is an arbitrary sequence of problems each one beginning with a problem control card. The problem control card contains, among other things, N, the number of market centers, M, the number of crops, NROAD, the number of highways, and NEWCASE, the number of re-scale runs to be made. A problem is re-scaled by specifying a new origin and a new scale factor for the maps. The original (reference) problem is then recomputed with updated coordinates for the market centers and highways. As N must be greater than zero, a data card giving the market center coordinates always follows the problem control card. If M > 0, the scale/crop-yield cards followed by the crop parameter cards appear next in sequence. If NROAD > 0, the highway data cards (one per highway) are next. Finally, if NEWCASE > 0, the re-scaling cards (one per re-scale for a total of NEWCASE) are included. It should be noted that program execution will be terminated and an error message will be printed out under the following conditions of the input data:

1) $N \leq 0$ or $N \geq$ MAXN, where MAXN is either 4 or 10;

2) M > MAXM, where MAXM is either 4 or 12;

3) NROAD > MAXR, where MAXR is either 2 or 9;

4) a highway of zero length is specified, i.e. the initial and final coordinates are identical.

The program output consists of A] an echo check of data inputs, B] from one to four maps (depending upon the problem control card parameters), and C] summary tables giving areas in cultivation and levels of economic rent (if M > 0). The maps are: 1) a location of market centers map; 2) a sphere of influence of roads map; 3) a land use map; and 4) a market areas map. The first map always appears in the output, and the second appears if NROAD > 0. Maps 3) and 4) are printed if M > 0.

The market center location map contains an X at the position of each town appearing within the previously defined rectangular area. Each highway or portion of a highway (if any) within this

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rectangular region is also displayed with identifying numbers at the initial and final coordinates. An option exists for selecting the highway symbol. It may be either a dot (·), an asterisk (*), or a plus (+). The default option is a dot.

The sphere of influence of a highway is the set of cells for which the average effective distance from the cell to all N market centers is less than the average airline distance to the towns or the average effective distance to the towns using all other highways. A cell within the sphere of influence of a highway is identified on the map with the highway number. Those cells whose minimum average distance is the average airline distance are left blank. If the average effective distances are equal for two highways with respect to a given cell, an equal (=) sign is printed in the cell.

The land use map displays the regions of crop cultivations with a letter symbol printed in each cell associated with a crop. The market areas map indicates with a number symbol over the same region the market where the crops are sold. An equal (=) sign is printed in those cells where it is equally profitable to grow either of two crops or sell the product at either of two markets, respectively. Regions for which the rent is ≤ 0 are left blank.

If M>0, distances on the map may be scaled by a multiplying factor, SCALE. This factor has meaning only if M>0 as a result of the effect of distance on the rent computations. All points on or off the maps are specified in terms of integer coordinates so that a unit increment in either the horizontal or vertical direction corresponds to a distance of 1/10" on the printed output. The factor SCALE is a non-negative floating point number (if SCALE = 0.0, it is reset to 1.0) which assigns a physical distance to this unit increment. The physical distance may be either abstractly defined or in feet, miles, etc.; and 10.0*SCALE is the distance per inch of the printed output maps. This distance scale is printed at the bottom of each map if M>0. To obtain maps of different regions within the same problem requires the modification of the coordinates of all market centers and highways and/or SCALE leaving the remaining data the same. In this case physical distance must be invariant, i.e. modifying the value of SCALE or shifting the origin necessarily causes a consistent modification of the integer coordinates which will preserve actual distance. Thus,

$$sd = c$$

where

c = the physical distance and is constant
s = the scale factor
d = distance on the map

Let us assume that data has been prepared for a problem which will produce output maps in a coordinate system (x,y) and that maps of the same problem in a coordinate system (x',y') are desired. Also, let s and s' represent the distance scales in the unprimed and primed systems; and let (x_0,y_0) be the unprimed coordinates of the origin of the primed system. If (x_1,y_1) represents an arbitrary point in the unprimed system, its corresponding point in the primed system is (x_1',y_1') where,

$$x_1' = s/s' \ (x_1 - x_0)$$

$$y_1' = s/s' \ (y_1 - y_0)$$

All coordinates of market centers and highways must be transformed as above and rounded off to closest integer values. Note that the new coordinate system is completely specified by x_0, y_0, and s'.

The following example illustrates the salient points of the above discussion. Assume that data has been prepared for a problem having a market center located off the maps at $(x_1,y_1) = (120,-20)$ with a scale of 4.0. For the <u>same</u> problem it is desired to obtain maps of the region surrounding the market center and having a scale of 3.0. Let $(x_0,y_0) = (90,-40)$. Then

$$x_1' = 4/3 \ (120 - 90) = 40$$

$$y_1' = 4/3 \ (-20 - (-40)) = 26\ 2/3 = 27$$

and the new data would include the point (40,27) as the location of the market center.

The program contains an option which will <u>automatically</u> re-scale any problem. The problem as specified by the data immediately following the problem control card will be called the reference case. Each re-scale data card which follows a reference case contains the coordinates of a new origin and a new scale factor. The coordinates of the market centers and highways in the reference case are saved and new coordinates are computed relative to the reference problem for each re-scaling. Re-scaling may be done if M = 0, in which case the reference scale factor is assumed to be 1.0. The number of the reference case is printed for each re-scaling along with the x and y coordinates of the new origin. The scale ratio, i.e. the ratio of the reference scale factor to the new scale factor (s/s') is also printed. Under the existing input data structure a problem may be re-scaled as many as ninety-nine times. The user is cautioned not to specify a scale factor on a re-scale card so large that a highway is effectively reduced to zero length, i.e. the initial and final coordinates coincide. This will cause execution to be terminated.

Deck Make-Up: A) Basic structure [CDC 6400]

1) Systems cards
2) EOR card
3) Program decks
4) EOR card
5) Data deck
6) EOR card
7) EOI card

B) Data deck structure - The following sequence is repeated once for each problem:

1) Problem control card
2) Market center location card(s)
3) Scaling and crop yield card(s) [if M > 0]
4) Crop parameter card(s) [if M > 0]
5) Highway parameter card(s) [if NROAD > 0]
6) Re-scale card(s) [if NEWCASE > 0]

Card Format: Problem Control Card - FORMAT (5I2, 7A10)

Cols. 1 - 2 N = number of centers [$1 \leq N \leq 10$ if password is used; $1 \leq N \leq 4$ otherwise]

Cols. 3 - 4 M = number of crops [$M \leq 12$ if password is used; $M \leq 4$ otherwise]

Cols. 5 - 6 NROAD = number of highways [$NROAD \leq 9$ if password is used; $NROAD \leq 2$ otherwise]

Cols. 7 - 8 ISYM < 0 if highways are to be displayed on all maps; ISYM ≥ 0 if highways are to be displayed on the location of market centers map only. $|ISYM| = 1$ if highway symbol is to be an asterisk (*) and $|ISYM| = 2$ if the symbol is to be a plus (+). The highway symbol will be a dot(·) for any otner value of ISYM.

Cols. 9 - 10 NEWCASE = number of re-scale cards for the current problem (if > 0). If $NEWCASE \leq 0$, the problem is not to be re-scaled.

Cols. 11 - 70 Any title information

Cols. 71 - 80 Any word with up to 10 symbols. If this word is the password, the limits on the number of centers, crops and highways are increased.

Market Center Location Card(s) - FORMAT (8I10)

The X and Y coordinates are specified pairwise in integer format at field width increments of 10 in the following sequence:

X_1, Y_1, the X and Y coordinates of center 1

X_2, Y_2, the X and Y coordinates of center 2

.

.

.

.

X_N, Y_N, the X and Y coordinates of center N

Note that $[\frac{N - 1}{4}] + 1$ cards are required.*

Scaling and Crop Yield Card(s) - FORMAT (8E10)†

Cols. 1 - 10 SCALE = the distance scale factor. Ten times this number is the scale printed below each output map. If SCALE = 0.0, it will be reset to 1.0.

Cols. 11 - (Y(I), I = 1, M) = the crop yields per unit area for crops 1 through M, respectively, at field width increments of 10.

Note that [M/8] + 1 cards are required.*

Crop Parameter Card(s) - FORMAT (3E10)†

Cols. 1 - 10 the unit market price
Cols. 11 - 20 the unit production cost
Cols. 21 - 30 the unit transportation cost per unit distance

Note that there is one data card per crop per market center for a total of (N) (M) cards. The crop parameters for crops 1 through M with respect to market center 1 are read first; parameters of crops 1 through M with respect to market center 2 are read in next; etc.

Highway Parameter Card(s) - FORMAT (4I10, E10)†

Cols. 1 - 10 X coordinate of starting point
Cols. 11 - 20 Y coordinate of starting point
Cols. 21 - 30 X coordinate of ending point
Cols. 31 - 40 Y coordinate of ending point
Cols. 41 - 50 ALPHA, the ratio of on-highway to off-highway movement charges.

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Note that there is one data card per highway for a total of NROAD cards.

Re-scale Card(s) - FORMAT (2I10, E10)†

Cols. 1 - 10	X coordinate of new origin in reference system
Cols. 11 - 20	Y coordinate of new origin in reference system
Cols. 21 - 30	SCALE = the new distance scale factor. Ten times this number is the scale printed below each output map if M > 0. If SCALE = 0.0, it will be reset to 1.0.

* [X] means the integer part of X.

† The E10 FORMAT allows the user to specify input data either in F or E form within a field width of 10 columns. The decimal point must be punched in any case.

Note: The program LANDUSE requires the subroutines PROJCT and REGION and needs 50000_8 central memory locations to compile. The program only requires 33000_8 locations to load and go. It is written in FORTRAN IV for the CDC 6400 computer. Execution time is on the order of from 5 to 20 seconds for problems having up to 2 highways, but increases exponentially with an increase in the number of highways beyond 2. A strong factor affecting the amount of running time is the complexity, i.e. multiplicity of intersections, of the highway network.

Programmers: Bruce Anderson and Duane F. Marble, August 1970.

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APPENDIX B

THE GEOGRAPHY PROGRAM EXCHANGE

The Geography Program Exchange (GPE) has been established to assist universities and other non-profit organizations with the interchange of computer software which relates to problems of a geographic nature. The GPE operates on a self-sustaining basis with the assistance of a modest grant from the Mathematical Social Sciences Board. Its services are made available to qualified users anywhere in the world.

The GPE maintains a central file of specialized computer programs with associated documentation and test data sets, and makes copies of all or part of this material available to qualified users at cost. The programs held by the GPE represent specialized materials developed for use in geographic research and teaching; no attempt is made to duplicate standard statistical programs. Distribution of available programs is in the form of punched cards or BCD tapes, and associated documentation is also distributed in machine readable form. The GPE also produces a brief guide to its program holdings which is available without charge. Current program holdings are based mainly upon the specialized program libraries of the University of Iowa, Michigan, Michigan State and Northwestern University as well as individual programs from many other institutions. The GPE actively solicits programs and, if the program submitted appears to be of enough general interest, it will be added to those distributed. All software handled by the GPE is obtained and distributed on a non-royalty basis.

In addition, the GPE also publishes an irregular newsletter which, at present, is incorporated in *Current Research Notes in Quantitative and Theoretical Geography*. This is distributed without charge by the International Geographical Union Commission on Quantitative Methods and requests for copies should be directed to:

Professor Forrest R. Pitts
Social Science Research Institute
University of Hawaii
Honolulu, Hawaii 96822 U.S.A.

Although the GPE operates with limited resources, it does attempt to provide assistance to those departments and individuals who are beginning to make use of the digital computer as a research and teaching tool.

Overall management of the GPE is provided by a board consisting of Professors Duane F. Marble (Northwestern), Waldo R. Tobler (Michigan), Robert I. Wittick

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(Michigan State), and Forrest R. Pitts (Hawaii). Professor Wittick is in charge of operations and all inquiries relating to activities of the GPE should be directed to him at the following address:

Professor Robert Wittick
Computer Institute for Social Science Research
Michigan State University
East Lansing, Michigan 48823 U.S.A.

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APPENDIX C

KEYPUNCH INSTRUCTIONS

Vogelback Computing Center
Northwestern University
Evanston, Illinois

IBM 26 Printing Card Punch

General Operation:

Information is punched in a card by operating a typewriter style keyboard, which punches letters, digits, or special characters into card columns. The operator presses the "feed" button on the keyboard which moves a card down from the hopper. When the "register" button is depressed, the first column of the card is positioned under the punching station. The cards are punched from left to right, one column at a time. After each card is punched, the card is automatically positioned for the next column. After all 80 columns are punched, the card automatically is registered under the reading station, through which it passes -- column by column -- in phase with the card following it at the punching station. When the card at the punching station is released, the card at the reading station moves into the card stacker.

Because passage through the reading station is in phase with passage through the punching station, holes sensed at the read station can be duplicated into the following card passing under the punch station. The ability to duplicate information from card to card reduces the amount of manual punching needed. Data common to a group of cards may be punched into the first card of a group and duplicated into the remaining ones. Depressing the "duplicate" key can accomplish this, or it can be done automatically by the keypunch operating under preplanned control (drum or program card).

Other functions that can be put under automatic control are printing, skipping columns, and ejecting and feeding cards. According to the requirements of the card format, a pattern can be established so that the keypunch can skip columns, duplicate fields, or release the card when punching is finished but before column 80 is reached.

Instructing the keypunch to skip, duplicate, or release upon reaching certain column locations is known as programming. The operator programs the keypunch by punching a control card, wrapping the card around a cylinder or drum, and inserting the drum on a spindle in the machine. The holes in the card control the operation of the machine, causing it to perform specified functions automatically.

Operating Features

Card Hopper

The card hopper is located on the upper right side of the machine. The cards are placed in the hopper face forward, 9's down, and are fed front card first. A card is fed from the hopper to the card bed automatically or by depression of a card feed key. The first two cards to be punched must be fed by key depression, but all other cards in the hopper may be fed automatically, under switch control.

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Punching Station

Punching is performed at the first of two stations in the card bed through which the cards pass. To start an operation, two cards are fed into the card bed at the right of the punching station. As the second card is fed in, the first card is automatically registered for punching -- that is, it is positioned at the punching station.

Reading Station

The reading station, where the cards are read for duplicating, is located approximately the distance of one card to the left of the punching station. Each card that has been punched passes through the read station as the next card is being punched. The two cards move in synchronism, column by column, and information to be duplicated is transferred from the first card to the second. Reading from one card to another can be controlled, field by field, so that only the desired information is duplicated.

This feature eliminates card handling for the duplication of information from cards prepared during the punching operation. Card handling is necessary only when an operation requires duplication from prepunched master cards.

Card Stacker

The card stacker is located on the upper left side of the machine on a level with the hopper. After each card passes the read station, it is fed into the stacker automatically or by key depression. When the cards are removed from the stacker, they are in their original sequence.

Backspace K[illegible]

This key is located below the card bed between the read and punch stations. As long as it is held depressed, the cards at the punch and read stations are backspaced continuously until column 1 is reached. At the same time, the program card, which controls skipping and duplicating, is also backspaced.

Program Unit

Automatic skipping, automatic duplicating, and shifting from numerical to alphabetic punching and vice versa are controlled by the program unit. Each of these operations is designated by a specific code recorded in a program card. (See Program Card Codes) The program card is then fastened around a program drum and inserted in the machine, where it is read by a sensing mechanism. The drum revolves in step with the movement of the cards past the punch and read stations so that the program codes control the operations, column by column.

Program Control Lever

Operation of the program unit is controlled by the program control lever, located below the program unit. When this lever is turned on, the program sensing mechanism is lowered so that it rests on the program drum, and the codes punched in the program card control the various automatic operations.

Column Indicator

The indicator, located at the base of the program drum holder, indicates to the operator the next column to be punched. Refer to this indicator as a guide for spacing or backspacing to a particular column.

Keyboards - Number 3 - Combination alphabetic and numerical keyboard, plus 11 special characters.

The combination keyboards have the best features of both a typewriter and a numerical key punch. The letter keys are arranged for operation by the standard typewriter touch system, while the digit keys are placed so that a rapid three-finger touch system can be used. The usual numerical keys on a typewriter have been eliminated; instead, a group of dual-purpose keys at the right serves for digit as well as letter punching. This permits numerical punching with the right hand. The touch system for the ten numerical keys is: index finger for digits 1, 4, and 7; middle finger for digits 2, 5, and 8; and ring finger for digits 0, 3, 6, and 9. The punching of a digit or a letter with any of the combination keys depends upon the shift of the keyboard. For example, depression of the 4-J key punches a 4 when the keyboard is in numerical shift, but a J when in alphabetic shift. This shifting is similar to upper or lower case shifting on a standard typewriter and may be controlled automatically by the program unit or manually by key depression.

The fourth row of keys contains four special character keys at the left. These keys punch eight characters as shown on the key tops; four in numerical and four in alphabetic shift.

Program Card

The program card controls the automatic operations for the corresponding column of the cards being punched. The control punching required in the program card depends on the functions to be controlled, e.g., skipping, duplicating, and alphabetic punching.

Field Definition (12 punch "+")

A 12 punch (+) should be punched in every column except the first (left-hand position) of every field to be skipped, duplicated, or manually punched. These 12's serve to continue to the end of a field any skip or duplication started within that field.

Automatic Skip (11 punch "-")

An 11 punch in the first column of any field automatically starts a skip, which is continued over that field by the 12's punched in the remaining columns of the field. If a single column is to be automatically skipped, it is punched with an 11. This coding operates in conjunction with the automatic skip-duplicate switch, which must be on to start the skipping automatically.

Automatic Duplication (0)

A zero punched in the first column of any field automatically starts duplication, which is continued over that field by the 12's punched in the remaining columns of the field. If a single column is to be automatically duplicated, it is punched with a zero.

Alphabetic Shift (1)

When the program card is in the machine, the combination keyboard is normally in numerical shift, and depression of any one of the two-purpose keys causes a figure to be punched. To punch a letter, the combination keyboard must be shifted for alphabetic punching. This shifting is performed automatically by a 1 in the program card in each column of the alphabetic field.

Program Card Codes

Code	Function
12 +	Field Definition
11 -	Start Automatic Skip
0	Start Automatic Duplication
1	Alphabetic Shift
2	Left Zero Print
3	Print Suppression

Program Drum

The program card is mounted on a program drum for insertion in the machine. The program drum has a clamping strip to hold the card, and a handle on the top to tighten or release the strip. To fasten a card around the drum, take the following steps:

1. Hold the drum in a horizontal position with the handle to the right. Turn the handle away (counter-clockwise) as far as it will go. This loosens the smooth edge of the clamping strip.

2. Insert the column 80 edge of the card under the smooth edge of the clamping strip. Two alignment check holes in the clamping strip make it possible to see that the card is flush with the metal edge under the strip. The card should be positioned so that the 9's edge is against the rim of the drum.

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3. Turn the handle to the center position. This tightens the smooth edge of the clamping strip and loosens the toothed edge.

4. Wrap the card tightly around the drum and insert the column 1 edge under the toothed edge of the clamping strip.

5. Turn the handle toward you (clockwise) as far as it will go. This fastens the toothed edge of the clamping strip. The drum is now ready to be inserted in the machine.

To remove a card from the drum, the above procedure should be followed in the reverse order.

With the program sensing mechanism raised, the drum is placed on the spindle under the center cover of the punch, positioned so that the aligning pin falls in the aligning hole in the column indicator dial. The program control lever is turned on to lower the reading star wheels onto the program card, and the release key is depressed to engage the reading mechanism fully. Whenever the drum is to be removed, the program control lever must first be turned off to raise the star wheels.

When the punch is operated without program control, the keyboard is in alphabetic shift. When the program control lever is turned on, the keyboard is in numerical shift for all columns except those punched with the alphabetic field coding in the program card. If it is necessary to punch digits with the program off or in an otherwise alphabetic field, the numerical shift key is held down while the digit keys are depressed. Similarly, when it is necessary to punch some letters in an otherwise numerical field, the alphabetic shift key is held down while the letter keys are depressed.

Skip Key

The purpose of this key is to skip any field that is coded with 12's in the program card. Depression of the key starts the skip and the 12's, in succeeding columns of the field, continue the skip for the rest of the field.

Dash Skip (or) Dash Key

When the keyboard is in numerical shift, depression of this key punched an 11 hole and causes skipping for the rest of the field as determined by the successive columns punched 12 in the program card. When the keyboard is in alphabetic shift, depression of this key punches an 11 hole but does not cause skipping.

Duplicate Key

Any information, manually punched in one card and common to one or more successive cards, can be duplicated by use of this key. Depression of this key at the beginning of a field starts duplication, and the 12's punched in the program card continue the duplication for the rest of the field.

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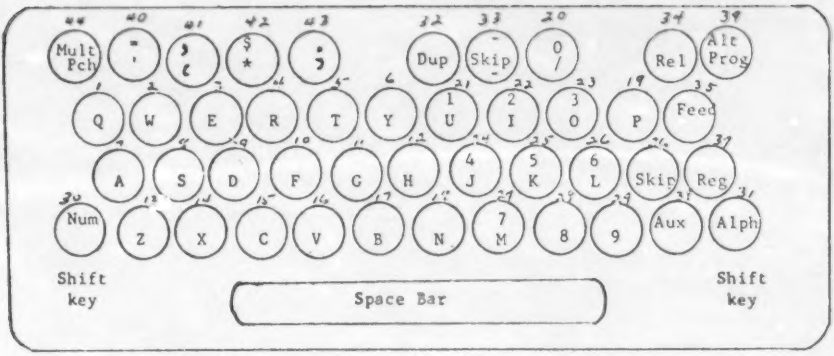
Keyboard Summary



Punching Keys

Keys 1-18 can be depressed only when the keyboard is in alphabetic shift to punch the letters indicated. If one of these keys is depressed while the keyboard is in numerical shift, the machine locks. Operation can be resumed by releasing the card, or by depressing the alphabetic shift key which will cause the letter to be punched.

Combination keys 19-29 can be depressed when the keyboard is in either numerical or alphabetic shift to punch the characters controlled by that key.

Keys 40-43 punch multiple digits for eight special characters. They can be depressed when the keyboard is in either numerical or alphabetic shift.

Space Bar

The space bar can be depressed at any time in a manual field to cause spacing over one column of the card.

Functional Keys

30 NUM (numerical shift) shifts the combination keyboard into numerical position as long as it is held down.

31 ALPH (alphabetic shift) shifts the combination keyboard into alphabetic position as long as it is held down. It is normally used to permit the punching of letters in an otherwise numerical field.

32 DUP (duplicate) causes punching by reading from the preceding card.

34 REL (release) causes the cards at the punch and read stations to be advanced completely past those stations. Fields programmed for automatic duplication beyond the point of release are punched in the card before release is completed.

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35 FEED (card feed) causes a card feed cycle:

1. Feeds a card from the hopper.
2. Registers the cards at the punch and read stations.
3. Stacks the card from the left of the card bed.

36 SKIP causes skipping of the field for which it is depressed.

37 REG (card register) is used primarily when inserting cards manually.

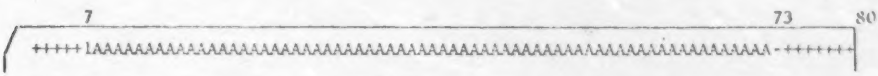
44 MULT PCH (multiple punch) is held down to permit the punching of more than one digit in a column. The keyboard is in numerical shift when this key is depressed.

(Note: An example of the use of the multiple punch key is:

$\frac{7}{8}$ END OF RECORD

* *

Sample program card for Fortran statements. (Note that "A" punch defines an alphabetic field length.)

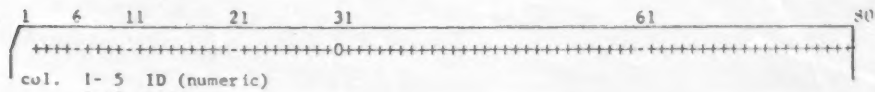


col 1-5 numeric (statement number)
6 numeric (continuation)
7-72 alphabetic (to punch numeric information, depress NUM key)

73-80 automatic skip and release of card

* *

Sample program card for data cards.



col. 1- 5 ID (numeric)
6-10 Skip
11-20 Numeric
21-30 Skip
31-60 Duplicate preceding card (numeric)
61-80 Skip and release card

---

* Information for this instruction sheet was obtained from the IBM publication IBM Reference Manual 24 Card Punch 26 Printing Card Punch, Form A24-0520, 1959, and Kenneth Janda, Data Processing, Northwestern University Press, 1965, pp. 48-51.

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